An Evaluation Model for Selecting Cloud Services from Commercially Available Cloud Providers

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Abstract—Selecting the appropriate cloud services and cloud providers according to the cloud users requirements is becoming a complex task, as the number of cloud providers increases. Cloud providers offer similar kinds of cloud services, but they are different in terms of price, quality of service, customer experience, and service delivery. The most challenging issue of the current cloud computing business is that cloud providers commit a certain *Service Level Agreement* (SLA), with cloud users, but there is little or no verification mechanisms which ensure that cloud providers are providing cloud services according to their commitment. In the current literature, there is a lack of an evaluation model which provides the real status of cloud providers for the cloud users. In this paper, an evaluation model is proposed, which verifies the quality of cloud services delivered for each service and provides the service status of the cloud providers. Finally, evaluation results obtained from cloud auditors are visualized in an ordered performance heat map, showing the cloud providers in a decreasing ordering of overall service quality. In this way, the proposed service quality evaluation model represents a visual recommender system for cloud service brokers and cloud users.

Index Terms—Cloud Computing; Service Measurement; Service Verification; Service Evaluation Model; Recommender System ; Provider Selection ; Performance Heat Map

I. Introduction

With the increasing number of Cloud Service Providers (CSPs), selecting the appropriate CSPs according to their requirements is a complex and tedious job for cloud users. During the service negotiation process, the cloud user and the cloud provider agree on the contract which includes the terms and conditions to be followed by both parties. This contract is called *Service Level Agreement* (SLA). SLAs are composed of different *Quality of Service* (QoS) rules, which are the obligations that have to be followed by the cloud providers [1]. A Cloud provider is a subject to contractual compensations in case of SLA breaches. This penalty is as essential to the SLA as guarantees, a notion essential to the very concept of using SLAs as instruments for providing some level of determinism in business relations [2]. Thus an SLA should also describe what shall happen when something goes wrong, that is when SLA is violated.

In the current practice, cloud providers offer SLA templates on their websites, and cloud users agree on the corresponding SLA terms and conditions while subscribing the cloud services. If a cloud provider does not meet the committed service offer, cloud users are eligible to receive a Service Credit. The service credit is a credit calculated as a percentage of the total charges paid by the cloud user. The received compensation may be however negligible compared to the losses caused by the insufficient QoS.

Due to the lack of the standardized SLA template in cloud computing, cloud providers are not legally obliged to offer any specific SLA template. Majority of the cloud providers offer monthly uptime (in percents) as the main QoS indicator. Other attributes are not clear in terms of SLA service and monitoring. In many cases, cloud providers offer similar or identical characteristics of services such as service availability, reliability, but they exhibit differences in terms of price, quality of service, service delivery and customer experience. This specific adds an extra burden on cloud users and cloud brokers when they select cloud services from cloud providers [3].

In this paper, a service evaluation model which measures cloud services delivered by commercially available cloud providers using cloud auditors is presented. It verifies the service delivery compliance with the committed SLA offer, however verification of services is limited to the measurable parameters accessible from the majority of cloud providers. Those values are further visualized in a performance tableau format showing the evaluated cloud service providers in a decreasing order of overall performance. The main contributions of the paper are:

1) Measurement of cloud services delivered by commercially available cloud providers.
2) Verification of cloud services delivered by cloud providers according to SLAs offered by cloud providers.
3) Evaluation of cloud providers on a hierarchy of performance criteria.
4) Multiple criteria ranking of cloud providers that aids cloud users and cloud brokers in selection of the appropriate cloud services.

The paper is organized as follows: Section II describes the related works in CSP ranking and service selection. Section III provides the framework for SLA assured brokering and recommendation model. The SLA attributes measured to evaluate the CSPs are briefed in section IV. The measured parameters and verification of cloud services with offered SLA are presented in section V. A novel CSP selection aid is

proposed in VI. Service selection recommendation is discussed in section VII. Conclusions and future works directions are described in section VIII.

II. RELATED WORKS

In the current growing cloud computing business, selecting the best cloud service from appropriate cloud providers is very complex and challenging for the cloud users. There is a multitude of works that employ optimization to achieve this goal [4], however they usually require certain input data, and their solutions are applicable for the current situation. The multi-objective optimization attempts [5] overcome some of these limitations, but in turn they provision a Pareto front of optimal solutions, which creates a consecutive problem of the selection of the final solution .

The selection of the best web services according to consumers' opinion for the web service selection based on consumer's vague perception is introduced by Wang [6]. Practically, web services and cloud services can not be evaluated only on the basis of consumers' perception, because user may not receive actual service delivered by cloud provider due to network problem, e.g. limited bandwidth, or other problems.

For the ranking of cloud services SMICloud [7] has proposed a framework for comparing and ranking cloud services. It considers only quantifiable SLA attributes defined by Cloud Service Measurement Index Consortium (CSMIC) [8], and does not consider the qualitative attributes. SMICloud is based on an analytic hierarchy process (AHP) [9]. The main difficulty in the provider ranking based on the AHP technique is assigning the hierarchy of SLA attributes. In practice, each SLA attributes are important and dependent on each user's preferences.

The authors in CloudCmp [10] have proposed a framework to compare the performance of different Cloud services such as Amazon EC2, Windows Azure and Rackspace, but it only compares the low-level performance metrics of Cloud services such as CPU utilization and network throughput etc. Such low-level performance metrics could be further used to create models of high-level system properties, such as power consumption or performance [11], but it has not been tackled.

Hoi Chan et. al [12] have proposed ranking and mapping of cloud computing applications. It is limited to few SLA attributes and does not provide a basis on which the weights of cloud services are assigned to each cloud provider. Service Ranking System [13] searches SLA offers provided by cloud providers rather than the quality of delivered services to rank the cloud providers. The authors in CloudRank [14] propose a cloud ranking algorithm based on greedy method which considers few functional parameters to rank the cloud providers and does not consider the delivered services in their framework. The cloud service selection process based on consumer experience and involving the third party to avoid a biased assessment of cloud services from users has been proposed by Qu et. al [15], however it does not cover the performance measurements from cloud providers. To the best of our knowledge, there is no evaluation framework which
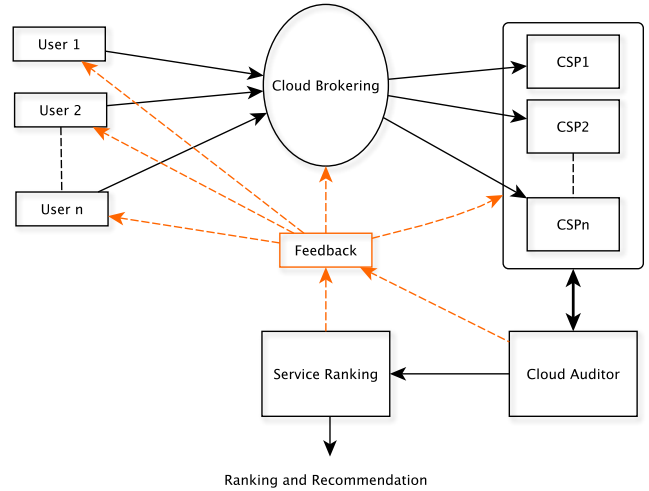

Fig. 1. Proposed Framework for SLA-based Service Brokering

selects and ranks the commercially available cloud providers based on their delivery of service compared with the SLAs offered by them.

III. SLA BASED CLOUD SERVICE BROKERING FRAMEWORK

Fig. 1 shows the overall framework for SLA assured brokering based on the service delivery of cloud providers and the service experience of cloud users. Cloud auditors measure the service performance delivered by cloud providers. The Cloud Auditor module contains cloud auditors ($Auditor_1$ and $Auditor_2$). In our case both cloud auditors collects performance of commercially available cloud providers. The Cloud Auditor module also compares the service delivered by cloud providers with SLA commitment to cloud users. If a cloud provider is delivering services according to its commitment, the cloud provider is verified. Otherwise the cloud provider is not verified.

The Service Ranking system ranks and recommends the cloud providers based on their SLAs and effective service delivered by cloud providers. The service ranking and recommendation system provides overall performance ranking of cloud providers. Based on the information provided by the Service Ranking module, the Feedback module distributes information about each cloud provider to cloud broker and cloud users. To improve the quality of performance measurement and customer feedback, multiple cloud auditors and cloud users can be involved. Additionally, in case of information from one source, other sources still can provide the status of cloud providers' services. Different independent auditors also make the system more trustworthy. The cloud broker collects the requirements of cloud users and recommends cloud services from different cloud providers based on ranking and service performance provided by the feedback system. The SLA-assured cloud brokering is however out of scope in this paper.
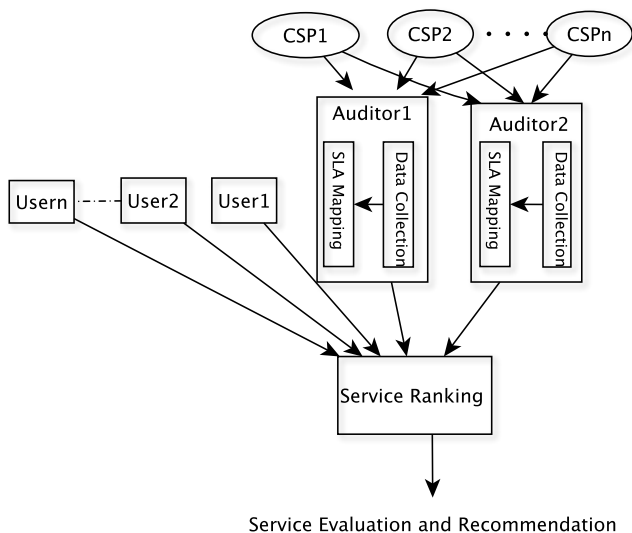
Fig. 2. Recommendation Model

Overview of our solution is shown in Fig. 2. Low-level data are collected from commercially available cloud providers. These values are mapped to SLA parameters so that the measured performance can be compared with SLA offer by cloud providers. The Cloud Auditor (module of service monitor and service verifier) verifies the services delivered by cloud providers. The service ranking module collects the service measurement and user experience from cloud auditors and cloud users respectively, to provide cloud provider ranking and service recommendation to the cloud users.

IV. Cloud computing service metrics

Cloud service metrics provide knowledge about characteristics of a cloud service by their definitions (e.g. expression, unit, rules) and the values resulting from the observation of the property [16]. It is necessary to define a set of specific metrics, on basis of which cloud services are selected. The metrics play an important role in the evaluation, as well as the selection of the cloud providers. In case of cloud computing, there are no standard, uniform SLA metrics and it is not mandatory for cloud providers to follow any specific metric. It is thus more challenging to consider all the important aspects of a standard cloud computing SLA.

Some initiative works have been carried out to define the SLA metrics in cloud computing. The selected in this study SLA metrics used to assess the cloud services from appropriate cloud providers comes from the literature. Guide to Cloud SLA [17], Service Measurement Index (SMI) defined by CSMIC, TM Forum [18], NIST Cloud Computing Standards Roadmap [16], Cloud Computing Service Level Agreements [19], OCCI working group [20] have provided their important contributions to standardize the SLA metrics in cloud computing.

In this work, five main performance criteria are chosen as important requirements to measure QoS for the cloud

TABLE I
CRITERIA AND SUB-CRITERIA FOR EVALUATING CLOUD SERVICES

Criteria	Sub-criteria	Short Name
Availability (C1)	Uptime(c11)	upT
	Downtime(c12)	dwT
	Outage Frequency(c13)	ouT
Reliability (C2)	Load Balancing(c21)	LB
	MTBF(c22)	$MTBF$
	Recoverable(c23)	Rcv
Performance (C3)	Latency(c31)	Lat
	Response time(c32)	rsT
	Throughput (c33)	tpT
Cost (C4)	Storage Cost (c41)	stC
	VM instance cost(c42)	snC
Security (C5)	Authentication(c51)	auT
	Encryption(c52)	enC
	Audit-ability(c53)	auD

users: *Availability*, *Reliability*, *Performance*, *Cost* and *Security*. Under each main criteria, subcritera, which are directly measurable from cloud provider premises, are defined. To cover measurable and non-measurable preferential aspects in the evaluation model, we have selected five SLA attributes; *Performance*, *Availability* and *Reliability* as functional criteria, *Security* and *Cost* as a non-functional criteria. To map measured sub-criteria to SLA attributes, we use mapping rules. For example, if service downtime and uptime of particular cloud provider are known then they are mapped into an *Availability* performance as follows:

$$A_v = \frac{uptime}{uptime + downtime} \qquad (1)$$

Mapping to SLA criteria from measured sub-criteria values depends on the nature of services and types of service used. Definitions [1] and mathematical formula provided in [21], [22], [23] are used in criteria mapping.

V. Verification and Evaluation of Cloud Providers

A. Service Performance Measurement

To evaluate the service performance of the eleven selected cloud providers (see Table II), two cloud auditors are used: $CloudAuditor_1$, $CloudAuditor_2$. Evaluation data presented in Table III and Table IV was collected over a period of seven days. Internet connection between local test environment and the cloud providers is presented in Table II. $CloudAuditor_1$ uses CloudHarmony (www.cloudharmony.com) monitoring tool and $CloudAuditor_2$ uses monitis (www.monitis.com) monitoring tool. Service performance is measured for all cloud users based in Luxembourg. The verification of cloud services of a cloud provider with a committed SLA is difficult because cloud providers often do not provide sufficient information in their SLA and they are not legally obliged to provide all the information in their SLA. The selected cloud providers provide only monthly uptime of service delivery.

All services are measured on the basis of SLA attributes defined in Table I. Missing data are represented as 'NA'. Measurements of cloud service performance of each cloud

TABLE II
INTERNET CONNECTION BETWEEN LOCAL TEST ENVIRONMENT AND CLOUD PROVIDERS

SN	Cloud Provider	Short Name	Website	Downlink (Mbps) (256 Kbps-10 Mbps)	Latency (ms)
1	Microsoft Azure	MS	https://www.azure.microsoft.com	28.15	46.5
2	GMOCloud -US	GMO	https://www.us.gmocloud.com	1.31	506
3	HP Cloud	HP	https://www.hpcloud.com	22.64	16
4	Amazone S3	Amz	https://www.aws.amazon.com/s3/	36.3	40.5
5	Rackspace Cloud	Rsp	https://www.rackspace.com	3.07	630
6	Google Cloud Storage	Ggl	https://www.cloud.google.com	270.05	35
7	City Cloud	Cit	https://www.citycloud.com	8.62	89
8	Cloud Sigma	Sig	https://www.cloudsigma.com	24.13	215
9	Elastic Host	Ela	https://www.elastichosts.com	12.53	34
10	CenturylinkCloud	Cent	https://www.centurylinkcloud.com	254.79	36
11	Digital Ocean	Dig	https://www.digitalocean.com	4.22	190

TABLE III
SERVICE MEASUREMENT BY $CloudAuditor_1$

Cloud Provider	SLA offered Uptime %	Availability (C1) Uptime (c11) %	Downtime (c12) (min)	Outage (c13) (frequency)	Reliability (C2) Loadbalancing (c21)	MTBF (c22) (min)	Recoverable (c23)	Performance (C3) Latency (c31) (ms)	Response Time (c32)(ms)	Throughput(c33) (Mbps)	Cost (C4) Storage Cost (c41) (GB/month) $	Snapshot cost (c42) $	Security (C5) Authentication (c51)	Encryption (c52)	Availability (c53)	SLA Verification
Microsoft Azure	99.900	100.00	2.2	1	Yes	H	G	85.41	NA	41.82	0.048	NA	Yes	Yes	Yes	V
GMOCloud -US	99.900	44.70	2.3	1	Yes	10	G	210	NA	4.24	0.17	NA	Yes	Yes	Yes	NV
HP Cloud	99.950	100.00	0	0	Yes	VH	VG	21.38	NA	40.34	0.1	0.1	Yes	Yes	Yes	V
Amazon S3	99.990	100.00	1	1	Yes	H	G	47.73	NA	40.81	0.041	NA	Yes	Yes	Yes	V
Rackspace Cloud	99.900	100.00	0	0	Yes	VH	VG	84.59	NA	38.84	0.15	0.11	Yes	Yes	Yes	V
Google Cloud	99.000	100.00	1.15	1	Yes	H	G	45.42	NA	73.59	0.01	0.13	Yes	Yes	Yes	V
City Cloud	100.000	99.97	84	3	Yes	1 day	VP	93.19	NA	9.17	0.12	0.12	Yes	Yes	Yes	NV
Cloud Sigma	99.990	100.00	16.1	1	Yes	H	G	89.2	NA	8.45	0.13	0.13	Yes	Yes	Yes	V
Elastic Host	99.990	99.97	18.52	7	Yes	18hr	VP	84.05	NA	10.07	0.1	0.03	Yes	Yes	Yes	NV
CenturylinkCloud	99.999	99.99	12.9	10	Yes	3hr	P	83.73	NA	9.44	0.15	NA	Yes	Yes	Yes	NV
Digital Ocean	99.990	100.00	0.81	3	Yes	10hr	P	90.77	NA	10.15	0.2	NA	Yes	Yes	Yes	V

TABLE IV
SERVICE MEASUREMENT BY $CloudAuditor_2$

Cloud Provider	SLA offered Uptime %	Availability (C1) Uptime (c11) %	Downtime (c12) (min)	Outage (c13) (frequency)	Reliability (C2) Loadbalancing (c21)	MTBF (c22) (min)	Recoverable (c23)	Performance (C3) Latency (c31) (ms)	Response Time (c32)(ms)	Throughput (C33)(Mbps)	Cost (C4) Storage Cost (c41) (GB/month) $	Snapshot cost (c42) $	Security (C5) Authentication (c51)	Encryption (c52)	Availability (c53)	SLA Verification
Microsoft Azure	99.900	100	0	0	Yes	VH	VG	NA	179.6	NA	0.05	NA	Yes	Yes	Yes	V
GMOCloud -US	99.900	98.9	5	4	Yes	H	F	NA	282.1	NA	0.17	NA	Yes	Yes	Yes	NV
HP Cloud	99.950	99.9	3	2	Yes	VH	G	NA	176.49	NA	0.1	0.1	Yes	Yes	Yes	NV
Amazon S3	99.990	98.8	8	6	Yes	H	G	NA	505.71	NA	0.04	NA	Yes	Yes	Yes	NV
Rackspace Cloud	99.900	NA	NA	NA	Yes	NA	G	NA	NA	NA	0.15	0.11	Yes	Yes	Yes	V
Google Cloud	99.000	99.8	38	10	Yes	1day	G	NA	1190	NA	0.01	0.13	Yes	Yes	Yes	V
City Cloud	100.000	99.9	1	2	Yes	H	VG	NA	950.33	NA	0.12	0.12	Yes	Yes	Yes	NV
Cloud Sigma	99.990	100	0	0	Yes	VH	VG	NA	456.76	NA	0.13	0.13	Yes	Yes	Yes	V
Elastic Host	99.990	100	0	0	Yes	VH	VG	NA	59.81	NA	0.1	0.03	Yes	Yes	Yes	V
CenturylinkCloud	99.999	100	0	0	Yes	VH	VG	NA	949.91	NA	0.15	NA	Yes	Yes	Yes	V
Digital Ocean	99.990	99.3	35	5	Yes	1hr	G	NA	777.47	NA	0.2	NA	Yes	Yes	Yes	NV

provider are different for each cloud auditor because of different monitoring environment. In some cases the results are conflicting. The cost are directly referred from their websites. Service measurement from all selected cloud providers covers only the computing and storage services. Ranking order is based on the data gathered over a period of seven days. The actual ranking could change when considering a another or longer observation period or using input from other auditors. As a result, the presented results is only for explanatory purposes and should not be considered in any case as conclusive regarding the real QoS of the service providers.

Besides the evaluations of auditors, service experience by cloud users may be similarly included in the overall evaluation of cloud providers by the way of user surveys. This part is yet to be completed in our ongoing research work [24].

B. Service Verification

For the service verification, the measured value for criteria C_1 (see Table III and Table IV) is used, as all the selected cloud providers offer monthly uptime in SLA commitment. Measured value for criteria C_1 is mapped to criterion $Availability$ and compared with SLA offered by cloud providers. A value with red background shows the non-compliance of an SLA and is a subject to penalty for SLA violation. 'V' represents a positive verification of a service and 'NV' represents the negative verification of services. In data observed by $CloudAuditor_1$; *GMOCloud-US*, *City Cloud*, *Elastic Host* and *Centurylink Cloud* did not comply the service commitment as stated in their SLA. There is a significant gap between service offer and service delivered in *GMOCloud-US* and a comparatively less sever violation in the cases of *City Cloud* and *Elastic Host*. The difference is little for *Centurylink Cloud*, but it still did not manage to comply with its SLA. Similarly, *GMOCloud-US*, *HP Cloud*, *Amazon S3 City Cloud* and *Digital Ocean* did not comply the service commitment in service observation by $CloudAuditor_2$. There is a significant difference in offered SLA and delivered availability in *GMOCloud-US*, *Amazon S3* and *Digital Ocean* but it is less significant in *HP Cloud* and *City Cloud*. Unless cloud providers commit to all selected quality criteria services in

TABLE V
SERVICE MAPPING TO ordinal VALUE MEASUREMENT BY $CloudAuditor_1$

Cloud Provider	SLA offered Uptime %	Availability (C1)			Reliability (C2)			Performance (C3)			Cost (C4)		Security (C5)			SLA Verification
		Uptime (c11) %	Downtime (c12) (min)	Outage (c13) (frequency)	Loadbalancing (c21)	MTBF (c22) (min)	Recoverable (c23)	Latency (c31) (ms)	Response Time (c32)(ms)	Throughput (c33) (Mbps)	Storage Cost (c41) (GB/month) $	Snapshot cost (c42) $	Authentication (c51)	Encryption (c52)	Auditability (c53)	
Microsoft Azure	99.900	4.00	3	3	4	3	3	3	NA	4	4	NA	4	4	4	V
GMOCloud -US	99.900	0.00	3	3	4	1	3	2	NA	1	3	NA	4	4	4	NV
HP Cloud	99.950	4.00	4	4	4	4	4	4	NA	4	3	4	4	4	4	V
Amazon S3	99.990	4.00	3	3	4	3	3	4	NA	4	4	NA	4	4	4	V
Rackspace Cloud	99.900	4.00	4	4	4	4	4	3	NA	4	3	4	4	4	4	V
Google Cloud	99.000	4.00	3	3	4	3	3	4	NA	4	4	4	4	4	4	V
City Cloud	100.00	1.00	0	2	4	2	1	3	NA	2	3	4	4	4	4	NV
Cloud Sigma	99.990	4.00	2	3	4	3	3	3	NA	2	3	4	4	4	4	V
Elastic Host	99.990	2.00	2	1	4	3	1	3	NA	2	3	4	4	4	4	NV
CenturylinkCloud	99.999	2.00	1	0	4	2	2	3	NA	2	3	NA	4	4	4	NV
Digital Ocean	99.990	4.00	0	2	4	3	2	3	NA	2	3	NA	4	4	4	V

TABLE VI
SERVICE MAPPING TO ordinal VALUE MEASUREMENT BY $CloudAuditor_2$

Cloud Provider	SLA offered Uptime %	Availability (C1)			Reliability (C2)			Performance (C3)			Cost (C4)		Security (C5)			SLA Verification
		Uptime (c11) %	Downtime (c12) (min)	Outage (c13) (frequency)	Loadbalancing (c21)	MTBF (c22) (min)	Recoverable (c23)	Latency (c31) (ms)	Response Time (c32)(ms)	Throughput (c33) (Mbps)	Storage Cost (c41) (GB/month) $	Snapshot cost (c42) $	Authentication (c51)	Encryption (c52)	Auditability (c53)	
Microsoft Azure	99.900	4	4	4	4	4	4	NA	4	NA	4	NA	4	4	4	V
GMOCloud -US	99.900	1	3	3	4	3	2	NA	4	NA	3	NA	4	4	4	NV
HP Cloud	99.950	3	3	3	4	4	3	NA	4	NA	3	4	4	4	4	NV
Amazon S3	99.990	2	2	2	4	3	3	NA	3	NA	4	NA	4	4	4	NV
Rackspace Cloud	99.900	NA	NA	NA	4	NA	3	NA	NA	NA	3	4	4	4	4	V
Google Cloud	99.000	4	1	1	4	2	3	NA	2	NA	4	4	4	4	4	NV
City Cloud	100.00	3	3	3	4	3	4	NA	2	NA	3	4	4	4	4	NV
Cloud Sigma	99.990	4	4	4	4	4	4	NA	3	NA	3	4	4	4	4	V
Elastic Host	99.990	4	4	4	4	4	4	NA	4	NA	3	4	4	4	4	V
CenturylinkCloud	99.999	4	4	4	4	4	4	NA	2	NA	3	NA	4	4	4	V
Digital Ocean	99.990	2	1	1	4	2	3	NA	2	NA	3	NA	4	4	4	NV

C. Service Quality Evaluation

Table VII shows mapping of measured values into an ordinal performance scale consisting of five levels: from *Very Poor* (0) to *Very Good* (4). According to service commitment by cloud providers, multiple contract breaking points are defined and the granted service credit are offered according to the type of service violation. For example Amazon-S3 (www.aws.amazon.com/s3/sla) guarantee 99.95 % monthly uptime and it provides the service credit according to uptime %. If uptime % is less than 99.95 but equal to or greater than 99.0, the service credit is 10%. If uptime % is less than 99.0 the service credit is 30%. To consider all the values defined in SLA offer, minimum value (min_{value}), maximum value (max_{value}) and threshold value (th_{value}) are set to comparing SLAs of cloud providers. If a measured value is greater than max_{value} it is interpreted as Very Good (VG). If measured value is less than min_{value} it is interpreted as very poor (VP). If measurements of parameters are missing for cloud provider, it is mapped to *No Value 'NA'*. The third column in Table VII gives an interpretation of measured SLA parameter after comparing with offered SLA to ordinal values. The service mapping to ordinal value by $CloudAudior_1$ and $CloudAudior_2$ are presented in Table V and VI respectively.

As monitoring systems of $CloudAuditor_1$ and $CloudAudiotor_2$ are different, the mapping from measurement from Table III to Table V and from Table IV to Table VI are independent. Max_{value}, min_{value} and th_{value} values for each sub-criteria are defined for each cloud auditor. According to performance recorded in Table III and IV, ordinal values are mapped to Table V and VI, respectively. For example, in Table V, *Uptime* value of *Microsoft Azure* measured by $CloudAudior_1$ is $>max_{value}$, so it is mapped to ordinal level '4'. *Downtime*, *Outage Frequency*, *MTBF*, *Recoverable*, *Latency* are in the range of max_{value} and mapped to ordinal level '3'. *Costs* of the delivered services, gathering cost of storage and of VM instance, are taken from the providers' websites. Mapping of *Downtime*, *Outage Frequency*, *Latency*, *Response Time* and *Cost* is reverse to other sub-criteria mapping because their values should be minimized. The performance on the *Security* criterion considers the sub-criteria: *Authentication*, *Encryption*, and *Auditability*. Authentication protocol, encryption algorithm as well as logs provided during service usage are considered in order to evaluate the performance on these sub-criteria; two options: 'YES' or 'NO' are chosen as the evaluation scale. During our actual observation period, all of the eleven cloud providers were found satisfactory in terms of *Security*.

VI. CSP SELECTION AIDING APPROACH

The primary goal of this work is to help cloud users and cloud brokers with selection of the best cloud providers based on the service offer, delivery and user experience according to the defined SLA criteria. We follow a decision aiding approach proposed by Bisdorff [25], which involves the following steps:

1) Sorting the potential cloud providers into marginal performance quantiles classes;

their SLA, which is not the case in practice, it is not possible to provide the verification of service delivery for all SLA parameters. Instead of that, we propose an evaluation model to provide the status of commercial available cloud providers as a performance heat map. The visual performance heat map is used to recommend the cloud services to the cloud brokers and cloud users.

Linguistic terms	Ordinal Value	Measured Value
Very poor(VP)	0	$<min_{value}$
Poor (P)	1	min_{value}
Fair (F)	2	th_{value}
Good(G)	3	max_{value}
Very Good(VG)	4	$>max_{value}$
No Value	NA	Data not received

criteria	tpt	upT	MTBF	Lat	Rcv	ouT	dwT	stC	auD	enC	auT	snC	rsT	LB
weights	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00	2.00	2.00	2.00	3.00	2.00	2.00
tau(*)	0.62	0.59	0.54	0.45	0.43	0.43	0.43	0.36	0.00	0.00	0.00	0.00	0.00	0.00
Amz	4	4	3	4	3	3	3	4	4	4	4	NA	NA	4
MS	4	4	3	3	3	3	3	4	4	4	4	NA	NA	4
HP	4	4	4	4	4	4	4	3	4	4	4	4	NA	4
Rsp	4	4	4	3	4	4	4	3	4	4	4	4	NA	4
Ggl	4	4	3	4	3	3	3	4	4	4	4	NA	NA	4
Sig	2	4	3	3	3	3	2	3	4	4	4	4	NA	4
Dig	2	4	3	2	2	2	0	3	4	4	4	NA	NA	4
Ela	2	2	3	3	1	1	2	3	4	4	4	4	NA	4
Cent	2	2	2	3	2	0	1	3	4	4	4	NA	NA	4
Cit	2	1	2	3	1	2	0	3	4	4	4	4	NA	4
GMO	1	0	1	2	3	3	3	3	4	4	4	NA	NA	4

Color legend:

quantile	0.14%	0.29%	0.43%	0.57%	0.71%	0.86%	1.00%

(*) tau: Ordinal (Kendall) correlation of marginal criterion and global outranking relation.

Fig. 3. Heat map table by Auditor 1

2) Ranking the providers with multiple ordinal performance criteria;
3) Sorting the performance criteria in decreasing order of correlation with the previous ranking;
4) Visualizing the results in a performance heat map, ordering the potential CSPs from the best to the worst alternative.

A. Sorting marginal performances into quantile classes

Let X be the set of n potential cloud providers evaluated on a single real performance criteria. We denote $x, y, ...$ the performances observed of the potential decision actions in X. We call quantile $q(p)$ the performance such that $p\%$ of the observed n performances in X are less or equal to $q(p)$. The quantile $q(p)$ is estimated by linear interpolation from the cumulative distribution of the performances in X.

Consider a series: $p_k = k/q$ for $k = 0, ...q$ of $q + 1$ equally spaced quantiles, like *quartiles*: 0, 0.25, 0.5, 0.75, 1.0; *quintiles*: 0, 0.2, 0.4, 0.6, 0.8, 1.0; or *deciles*: 0, 0.1, 0.2, ..., 0.9, 1.0. The upper closed[1] q^k class corresponds to the interval $]q(p_{k-1}); q(p_k)]$, for $k = 2, ..., q$, where $q(p_q) = max_X x)$ and the first class gathers all data below $p_1 :] -\infty; q(p_1)]$. We call q-tiles a complete series of $k = 1, ..., q$ q_k quantile classes. For the performance heat map visualization, we associate to each of such p^k quantile class a color from *dark red* (worst) to *dark green* (best). See for instance the color legend for 7-tiles in Fig. 3, 4 and 5.

[1]The lower closed q_k class corresponds to the interval $[q(p_{k-1}); q(p_k)[$.

On each criteria we thus associate to the performance x of a cloud provider the color of the $q$tiles class to which belongs x. In Fig 3 again, we may thus observe that, for $CloudAuditor_1$, providers Amz, MS, HP, Rsp and Ggl show on sub-criteria tpT:*Performance*, Amz, MS, HP, Rsp, Ggl, Sig and Dig show on sub-criteria upT:*Availability*, HP and Rsp show on sub-criteria $MTBF$:*Reliability*, Amz, HP and Ggl show on sub-criteria Lat:*Performance* the best performance (4), whereas cloud provider GMO shows the worst performance in all the cases but cloud provider GMO shows worst performance only on sub-criteria Rcv:*Reliability* observed by $Auditor_2$ (see Fig 4). Similarly, in Fig. 5 we observed that, for combining result of both auditors, providers MS, AMZ, HP, Ggl and Rsp show on sub-criteria tpT:*Performance*, HP and Rsp show on sub-criteria $MTBF$:*Reliability*, Amz, HP and Ggl show on sub-criteria Lat:*Performance*, MS, Amz, HP, Ggl, Rsp, Sig and Gig show on sub-criteria upT:*Availability* and MS, $Cent$, Sig, Ela and Cit show on sub-criteria Rcv:*Reliability* the best performance (4), whereas provider GMO shows the worst performance in all the cases.

It is worthwhile mentioning that the quantiles sorting result has not to be taken as a kind of service rating. When observing in the heat map table that a CSP is evaluated best on a criteria, this only means that its performance is to be considered best relatively to the actually given set of potentially available CSPs. That is why, in case of identical evaluation of all potential CSPs, the performance is sorted into the best quantile for all of them (see last rows in Fig. 3, 4 and 5).

B. Multiple Criteria Ranking the CSPs

In Fig. 3 and 4, the CSPs appear ranked in decreasing order from the overall best to overall worst performing. This overall ranking is computed from bipolar outranking situations [26], where we consider that an alternative x *outranks* an alternative y when there is a *significant majority of criteria* that warrant a '*better than*' relation between them **and** there is no *considerable counter-performance* observed between when considering x in place of y.

When computing these outranking relation, we consider the five main performance criteria, namely *Availability*, *Reliability*, *Performance*, *Cost* and *Security* to be equally important; and all sub-criteria within each criterion are considered to be equisignificant. All criteria has the three sub-criteria except *Cost*(C_4). Weights are assigned to each sub-criteria to make equally significant for all criteria (see second row in Fig. 3, 4 and 5). Thus we obtain the following set of significance weights of the criteria and sub-criteria: $w_A = w_{c11} + w_{c12} + w_{c13} = w_R = w_{c21} + w_{c22} + w_{c23} = w_P = w_{c31} + w_{c32} + w_{c33} = w_C = w_{c41} + w_{c42} = w_S = w_{c51} + w_{c52} + w_{c53}$ where wc_{ij} represents the significance weight assigned to sub-criterion j under criterion i.

Considering eleven potential commercial cloud providers, alternative AMZ is ranked as the highest ranked cloud provider by $CloudAuditor_1$, whereas MS is ranked as the highest ranked cloud provider by $CloudAuditor_2$ (see Fig. 3 and 4), whereas the alternative GMO, respectively

criteria	ouT	dwT	MTBF	upT	Rcv	rsT	auD	enC	auT	snC	tpT	Lat	LB	stC
weights	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00	2.00	2.00	2.00	3.00
tau$^{(*)}$	0.75	0.70	0.60	0.55	0.53	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.07
MS	4	4	4	4	4	4	4	4	4	NA	NA	NA	4	4
Cent	4	4	4	4	4	4	4	4	4	NA	NA	NA	4	3
Ela	4	4	4	4	4	4	4	4	4	4	NA	NA	4	3
Sig	4	4	4	4	4	3	4	4	4	4	NA	NA	4	3
Cit	3	4	3	3	4	2	4	4	4	4	NA	NA	4	3
HP	3	3	4	3	3	4	4	4	4	4	NA	NA	4	3
Rsp	NA	NA	NA	NA	3	NA	4	4	4	4	NA	NA	4	3
GMO	3	3	3	1	2	4	4	4	4	NA	NA	NA	4	3
Ggl	1	1	2	4	3	2	4	4	4	4	NA	NA	4	4
Amz	2	2	3	2	3	3	4	4	4	NA	NA	NA	4	4
Dig	1	1	2	2	3	2	4	4	4	NA	NA	NA	4	3

Color legend:

quantile	0.14%	0.29%	0.43%	0.57%	0.71%	0.86%	1.00%

(*) tau: Ordinal (Kendall) correlation of marginal criterion and global outranking relation.

Fig. 4. Heat map table by Auditor 2

Dig, is ranked lowest by $CloudAuditor_1$, respectively $CloudAuditor_2$. Equally spaced 7 quantiles are considered in these heat maps, where, as mentioned before, dark green color indicates the relatively highest performance, whereas dark red indicates the relatively lowest performance.

Collective ranking of the potential eleven cloud providers is shown in Fig. 5 by grouping the evaluations of the two cloud auditors. In the collective ranking, evidently alternative MS is the highest ranked cloud provider, whereas cloud provider alternative GMO is the lowest ranked.

VII. Building a Service Selection Recommendation

In the previous section, we present an evaluation model of the delivered cloud service from eleven commercially available cloud providers (see Table II) which is based on their SLAs and service delivery. All the CSPs considered in this paper provide only monthly uptime in percents as the SLA compliance criterion. So, services *Availability* is taken into account for the verification and compared with the offered SLA commitments. In seven days observation many of the observed cloud providers did not comply their service *Availability* commitment. $CloudAuditor_1$ found four cloud providers who did not comply with their service commitment; whereas $CloudAuditor_2$ found five cloud providers who did not comply their service commitment. However, the results could change with a longer observation period.

Our selection recommendation consists of an ordered *Performance Heat Map* (see Fig. 5), which lists the potential set of CSPs sorted in decreasing order of overall evaluation. Remind that dark green, respectively dark red marked performances indicate best ones, respectively worst ones on each sub-criterion. Notice also (see ordinal correlation in row *tau* in Fig. 5) that *Performance* subscription *Throughput* (tpT), *Reliability* subscription *MTBF* and *performance* subscription *Latency* (Lat) evaluated by $CloudAuditor_1$, *Storage Costs* (stC) and *Availability* subscription *Uptime* (upT) evaluated by both auditors, do influence most the recommended *consensual* ranking. Similarly, sub-criterion *Throughput* (tpT), *Uptime*

(upT), *MTBF* and *Latency* (Lat) by $CloudAuditor_1$ (see Fig. 3) whereas *ouT*, *dwT*, *MTBF* and *upT* (see Fig. 4) in performance ranking, play dominance role in sorting order. *HP* is lower than *MS* in Fig. 3 because sub-criterion *stC* played dominant role in such case. Ranking order of *Cent* is upper than *Ela* in Fig. 4 because optimistic sorting approach is applied which makes assumption that many attributes with good performance results good performance in missing parameters. From the view of optimistic sorting approach, *Cent* and *Ela* have the same position.

The results of validation process and the heat maps shows the necessity to diversify the input for the recommendation system. The two used cloud auditors presents great discrepancy of results. The advantage of the heat map method is that it can aggregate results of multiple auditors, to present non-trivial change of results. Cloud users and brokers may select the most appropriate cloud services according to their requirements with tradeoff among different requirements; they can base on the ranking of all SLA attributes or base on individual service requirements. Despite that all these service verification and performance rankings are performed in the mentioned circumstances of data observation period, our performance heat maps show a convincing, consensually ranked multiple criteria performance of commercially available CSPs. This visual recommender tool may thus give important hints to cloud users and cloud brokers.

VIII. Conclusion and Future Works

The proposed evaluation model is a recommendation system that facilitates selection of the most appropriate cloud service provider to cloud users and cloud brokers. The following important aspects are addressed in cloud provider selection:

The proposed model considers both dynamic and static attributes during the selection of the cloud provider.

It verifies the cloud services delivered by cloud providers according to service details provided in the SLA commitment using multiple cloud auditors.

It proposes an individual heat map performance table and combined heat map performance table which provide the ranking of cloud providers and performance rank of each cloud provider in all the selected SLA attributes.

The performance table provides the recommended cloud providers for the selected SLA attributes and non-recommended cloud providers for those the SLA attributes. The recommendation can be provided to cloud users and cloud brokers to select cloud services according to their requirements or according to overall performance table.

In this paper, ranking and recommendation is based on the measurements of the service delivery. For the better performance of proposed framework, feedback of cloud users will be included in the future using cloud user survey [24]. This work is a part of work of the SLA-assured brokering and CSP certification framework [27]. SLA-assured broker uses the service recommendation table to propose the cloud services according to the cloud users requirements. Penalty calculation according to service violation by cloud providers is also a

criteria	tpT	MTBF	Lat	stC	stC	upT	upT	dwT	MTBF	Rcv	rsT	ouT	Rcv	ouT	dwT	auD	enC	auT	snC	tpT	Lat	LB	auD	enC	auT	snC	rsT	LB
weights	2.00	2.00	2.00	3.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00	2.00	2.00
tau(*)	0.50	0.48	0.38	0.36	0.36	0.33	0.32	0.31	0.29	0.23	0.20	0.18	0.16	0.15	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MS	4	3	3	4	4	4	4	3	4	3	4	4	4	3	4	4	4	4	NA	NA	NA	4	4	4	4	NA	NA	4
Amz	4	3	4	4	4	2	3	3	3	3	2	3	3	2	4	4	4	NA	NA	NA	4	4	4	4	NA	NA	4
Cent	2	3	3	3	3	2	4	1	4	2	4	4	4	0	4	4	4	NA	NA	NA	4	4	4	4	NA	NA	4
HP	4	4	4	3	3	4	3	4	4	4	3	3	4	3	4	4	4	4	NA	4	4	4	4	4	NA	NA	4
Ggl	4	3	4	4	4	4	3	2	3	2	1	3	3	1	4	4	4	4	4	4	4	4	4	4	4	4
Rsp	4	4	3	3	3	4	NA	4	NA	NA	3	4	NA	4	4	4	4	4	4	4	4	4	4	4	4
Sig	2	3	3	3	3	4	4	2	4	3	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4
Ela	2	2	3	3	3	2	4	2	4	1	4	4	4	1	4	4	4	4	4	4	4	4	4	4	4
Cit	2	2	3	3	3	1	3	0	3	1	2	3	4	2	4	4	4	4	4	4	4	4	4	4	4
Dig	2	2	3	3	3	4	2	0	2	2	1	3	2	1	4	4	4	NA	NA	NA	4	4	4	4	NA	NA	4
GMO	1	1	2	3	3	0	1	3	3	3	4	3	2	3	3	4	4	4	NA	NA	NA	4	4	4	4	NA	NA	4

Color legend:

quantile	0.14%	0.29%	0.43%	0.57%	0.71%	0.86%	1.00%

(*) tau: Ordinal (Kendall) correlation of marginal criterion and global outranking relation.

Fig. 5. Heat map table by All Auditors

potential future work, together with multi-criteria optimization of cloud brokering problems [4].

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