Cloud Testing- Issues, Challenges, Needs and Practice

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Abstract- **Cloud computing not only changes the way of obtaining computing resources (such as computers, infrastructures, data storage, and application services), but also changes the way of managing and delivering computing services, technologies, and solutions. Cloud computing leads an opportunity in offering testing as a service (TaaS) for SaaS and clouds. Meanwhile, it causes new issues, challenges and needs in software testing, particular in testing clouds and cloud-based applications. This paper provides a comprehensive tutorial on cloud testing and cloud-based application testing. It answers the common questions raised by engineers and managers, and it provides clear concepts, discusses the special objectives, features, requirements, and needs in cloud testing. It offers a clear comparative view between web-based software testing and cloud-based application testing. In addition, it examines the major issues, challenges, and needs in testing cloud-based software applications. Furthermore, it also summarizes and compares different commercial products and solutions supporting cloud testing as services.**

Keywords **- cloud testing, cloud-based software testing, testing cloud services, performance testing and evaluation, and scalability testing.**

1. INTRODUCTION

Cloud computing received significant attention recently as it changes the way computation and services to customers, For example, it changes the way of providing and managing computing resources, such as CPUs, databases, and storage systems. Today, leading players, such as Amazon, Google, IBM, Microsoft, and Salesforce.com offer their cloud infrastructure for services.

In 2010, Garner estimated that "the cloud service market will reach $150.1 billion in 2013". Similarly, Merrill Lynch also predicted that "cloud computing market will reach $160 billion in 2011". A recent study of Market Research Media forecasts that U.S. government spending on cloud computing is entering an explosive growth phase at about 40% CAGR over the next six years. Expenditure will pass $7 billion by 2015. Merrill Lynch estimates that within the next five years, the annual global market for cloud computing will surge to $95 billion.

Cloud computing not only brings new business opportunities, but also causes some major impacts on software testing and maintenance. A major impact is known as Testing as a Service (TaaS) in Clouds. TaaS cloud infrastructures is considered as a new business and service model, in which a provider undertakes software testing activities of a given application system in a cloud infrastructure for customers as a service based on their demands.

Although there are many published papers discussing cloud architectures, technologies, and models, design, and management, cloud testing and TaaS are still new subjects in software testing community. Hence, test engineers and quality assurance managers encountered many issues and challenges in testing modern clouds and cloud-based applications. Typical questions are listed below.

- What is cloud testing? And what are its special test process and scope, requirements and features?
- What types of cloud testing, environments, and forms do we need to perform for SaaSs/clouds and cloud-based applications?
- What are the major differences between conventional software testing and cloud-based software testing?
- What are the special requirements and distinct features of cloud-based software testing?
- What are the special issues, and challenges, and needs in cloud testing?
- What are the current practice, tools, and major players?

This paper is written to attempt to answer these questions. Its primary contribution is to provide a comprehensive tutorial and discussion about cloud testing. The paper introduces basic concepts about cloud testing, including its scope, objectives, distinct requirements, features, and benefits. In addition, it covers software testing issues and challenges for clouds and cloud-based applications in different perspectives from end-users, vendors, and application providers. Moreover, it presents a comparative view between cloud testing and conventional software

testing. Furthermore, the paper also covers several major players, and provides a comparative view on emergent technologies and tools in cloud testing as a service.

The rest of this paper is structured as follows. The next section discusses cloud testing concepts, including definitions, objectives, motivation and benefits, testing forms, types, and environments as well as activities. Section 3 is devoted to the discussion about what is new in cloud testing. It focuses on the new requirements, features, and differences between cloud testing and conventional software testing. Section 4 examines the primary issues, challenges, and needs in cloud testing. Section 5 reviews the existing emergent technologies, solutions, and tools in software cloud testing. Section 6 reviews the published papers in cloud testing and cloud-based software testing. Finally, the conclusion remarks are given in Section 7.

2. Understanding cloud testing

According to [1], cloud computing provides a cost-effective and flexible means through which scalable computing power and diverse services (computer hardware and software resources, networks and computing infrastructures), diverse application services, business processes to personal intelligence and collaboration are delivered as services to large-scale global users whenever and wherever they need.

Cloud computing is the next stage of the Internet evolution. A typical cloud must have several distinct properties: elasticity and scalability, multi-tenancy, self-managed function capabilities, service billing and metering functions, connectivity interfaces and technologies. In addition, a cloud supports large scale user accesses at distributed locations over the Internet, offers on-demand application services at anytime, and provides both virtual and/or physical appliances for customers. There are three types of clouds: a) private clouds, which are internal clouds based on a private network behind a firewall; b) public clouds, which are the clouds with public accessible services over the Internet; and c) hybrid clouds, which are made of different types of clouds, including public and private clouds.

2.1 What is Cloud Testing?

According to Wikipedia, "cloud testing is a form of software testing in which Web applications that leverage Cloud computing environments ("cloud") seek to simulate real-world user traffic as a means of load testing and stress testing web sites. The ability and costs to simulate Web traffic for software testing purposes has been an inhibitor to overall Web reliability." Based on our recent literature survey, there is a few of published papers addressing cloud-testing concepts, issues, and challenges.

The authors in [3] collected some other views about cloud software testing from practitioners in the real world. They are listed below.

> "Cloud testing basically aligns with the concept of cloud and SaaS. It provides the ability to test by leveraging the cloud, thereby bringing the same benefits that the cloud brings to customers…." (by Vinita Ananth, Director - APJ Region, HP Software-as-a-Service).

> "Testing in the cloud leverages cloud computing environments and seeks to simulate real-world user traffic as a means of load or stress testing Web sites. (By Nivedan Prakash)

> "Cloud testing is the answer to the less-than-realistic performance test that originates within the infrastructure of one of our clients. When we use cloud testing, we take advantage of hardware and bandwidth that more closely mimics our observed, real world conditions. Essentially, we execute the test in cloud-based infrastructure and bandwidth." (R V Ramanan, President – Global Delivery and Chief Software Architect, Hexaware Technologies)

In short, cloud-based software testing refers to testing and measurement activities on a cloud-based environment and infrastructure by leveraging cloud technologies and solutions. It has four major objectives.

- To assure the quality of cloud-based applications deployed in a cloud, including their functional services, business processes, and system performance as well as scalability based on a set of application-based system requirements in a cloud.
- To validate software as a service (SaaS) in a cloud environment, including software performance, scalability, security and measurement based on certain economic scales and pre-defined SLAs.
- To check the provided automatic cloud-based functional services, for example auto-provisioned functions.
- To test cloud compatibility and inter-operation capability between SaaS and applications in a cloud infrastructure, for example, checking the APIs of SaaS and their cloud connectivity to others.

2.2 Why is Cloud Testing Important?

Comparing with current software testing, cloud-based testing has several unique advantages listed below.

- Reduce costs by leveraging with computing resources in clouds – This refers to effectively using virtualized resources and shared cloud infrastructure to eliminate required computer resources and licensed software costs in a test laboratory.

- Take the advantage of on-demand test services (by a third-party) to conduct large-scale and effective real-time online validation for internet-based software in clouds.

- Easily leverage scalable cloud system infrastructure to test and evaluate system (SaaS/ Cloud/Application) performance and scalability.

IBM reported the experience on cloud testing in small business division, where a flexible and cost-efficient cloud-based development and testing environment is implemented, and cloud testing has demonstrated the following major benefits in [19].

- Reduce its capital and licensing expenses as much as 50% to 75% using virtualized resources.

- Reduce operating and labor costs as much as 30% to 50% by automating development and testing resource provisioning and configuration.

- Shorten its development and testing setup time from weeks to minutes.

- Improve product quality and reduce the detected defects by as much as 15% to 30%.

- Help to accelerate cloud computing initiatives with IBMCloudBurst™ implemented through QuickStart services.

2.3. Forms of Cloud-Based Software Testing

There are four different forms of cloud-based software testing. Each of them has different focuses and objectives.

- Testing a SaaS in a cloud – It assures the quality of a SaaS in a cloud based on its functional and non-functional service requirements.

- Testing of a cloud – It validates the quality of a cloud from an external view based on the provided cloud specified capabilities and service features. Cloud and SaaS vendors as well as end users are interested in carrying on this type of testing.

- Testing inside a cloud - It checks the quality of a cloud from an internal view based on the internal infrastructures of a cloud and specified cloud capabilities. Only cloud vendors can perform this type of testing since they have accesses to internal infrastructures and connections between its internal SaaS(s) and automatic capabilities, security, management and monitor.

- Testing over clouds – It tests cloud-based service applications over clouds, including private, public, and hybrid clouds based on system-level application service requirements and specifications. This usually is performed by the cloud-based application system providers.

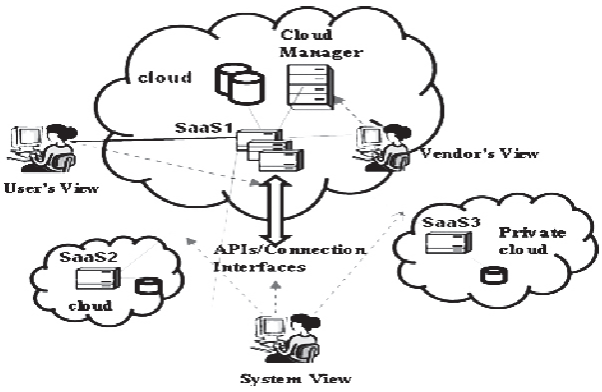

FIGURE 1 DIFFERENT VIEWS FOR CLOUD-BASED SOFTWARE TESTING

Figure 1 shows three different views of software testing in a cloud environment. The first is the vendor view, which presents the testing view from the engineers of a cloud vendor. They perform vendor-oriented software testing tasks. The next is the user view, which presents the consumer-oriented testing view from cloud-based application users through web-based user interfaces. They conduct testing and QA jobs to assure the quality

of provided application services in a system-oriented test view in a given cloud infrastructure where different cloud-based applications may interact with each other. They need to perform different testing tasks to assure the quality of the cloud-based application systems over clouds, such as cloud-based application integration, end-to-end system function testing, system performance and scalability over different clouds. The detailed testing tasks are discussed in the rest part of this section.

As shown in Figure 2, there are three types of cloud test environments:

- A cloud-based enterprise test environment, in which application vendors deploy web-based applications in a cloud to validate their quality in a cloud infrastrutcure.
- A private/public cloud test environment, in which vendors deploy SaaS applications SaaS in a private (or public) cloud to validate their quality.
- A hybrid cloud test environment, in which vendors deploy cloud-based applications on a hybrid cloud infrastructure to check their quality.

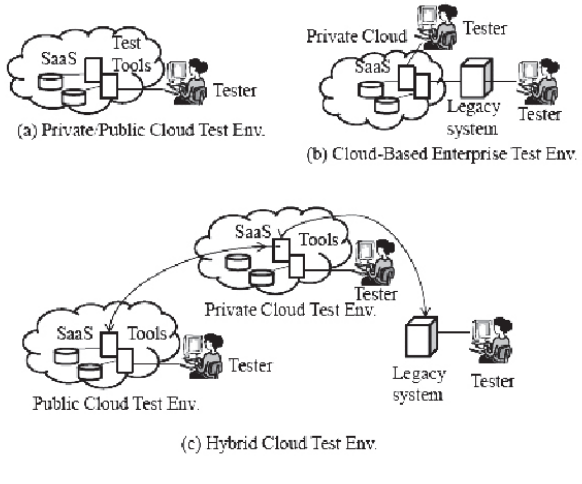

FIGURE 2 DIFFERENT TEST ENVIRONMENTS IN CLOUD

Table 1 identifies and presents the detailed tasks in three types of cloud testing below.

- ***Cloud/SaaS-oriented testing*** - This type of testing activities usually is performed inside a cloud by engineers of cloud/SaaS vendors. The primary objective is to assure the quality of the provided service functions offered in a cloud (or a SaaS program). These engineers must go through unit testing, integration, system function validation and regression testing, as well as performance and scalability evaluation. Since clouds and SaaS usually provide certain service APIs and connectivity interfaces to their customers, it is required task for engineers to validate these APIs and connectivity in a cloud environment. In addition, testing cloud-based or SaaS-based security services and functional features must be tested. Furthermore, performance testing and scalability evaluation in a cloud is very important and critical to cloud/SaaS vendors because this assures the quality of cloud elasticity to support SaaS and cloud services inside a cloud. Table 1 shows the detailed testing tasks.
- ***Online-based application testing on a cloud*** - This type of testing activities usually is performed to check online application systems on a cloud by using with cloud-based large-scale traffic and user accesses. This is a common usage of cloud technology to help current online application vendors to conduct online-based system function testing and performance evaluation on a cloud by taking the advantage of cloud environment so that diverse and scalable computing resources in a cloud can be used without using any in-house test laboratory. When applications are connected with legacy systems, the quality of the connectivity between the legacy systems and the under-test application deployed on a cloud must be validated. Table 1 shows the detailed tasks.
- ***Cloud-based application testing over clouds*** - This type of testing refers to the engineering activities performed to assure the quality of a cloud-based application crossing different clouds. When applications are developed to be deployed and executed over different clouds, new testing tasks are needed to assure its quality. Unlike the previous two types, the primary testing objective here is to assure the quality of the end-to-end application over clouds. This suggests that the system-level integration, function validation, performance evaluation, and scalability measurement must cope with different cloud technologies. This definitely complicates the tasks for checking system compatibility, interoperability, and connectivity between different clouds. Table 1 shows the detailed tasks.

TABLE 1
COMPARATIVE VIEW AMONG DIFFERENT PARTIES

Test Type	Testing focuses	Cloud/SaaS-Oriented Testing inside a Cloud	Online Application-Based Testing on a Cloud	Cloud-Based Application Testing over Clouds
Service Function Testing	GUI-based and API-based service functions	Testing SaaS/Cloud-based service functions inside a cloud	Testing online-based application service functions on a cloud	Testing cloud-based application service functions over a cloud infrastructure
Integration Testing	SaaS interactions and Cloud connections	Vendor-specific component and service integration inside a private/public cloud	Integration between online clients and back-end servers on a cloud	- End-to-end application integration over clouds - Integration with legacy systems over clouds
API and Connectivity Testing	API interfaces and connectivity protocols (HTTPS, REST, SOAP, RMI)	SaaS/Cloud API & connectivity testing in a cloud	Testing user-centered service APIs and connectivity on a cloud	Testing application service APIs and connectivity over clouds
Performance & Scalability Testing	Performance and scalability based on a SLA	SaaS/Cloud performance and scalability testing in a cloud based on the given SLA	User-oriented application performance and scalability testing on a cloud	End-to-end system-level performance and scalability inside/on/over cloud based on a given SLA
Security Testing	SaaS/Application data, processes, functions, and user privacy	SaaS/Cloud security features and user privacy in a cloud	User-oriented security and privacy on a cloud	System-level end-to-end security over clouds
Interoperability & Compatibility Testing	Validate different client interfaces and technologies and diverse compatibilities on different platforms and browsers	Testing Cloud/ SaaS compatibility, connectivity protocols and UI/client technologies inside a cloud	Testing user-centered interoperability, compatibility of platforms/ OS/browsers, and client technologies on a cloud	Testing application compatibility, end-to-end interoperability and application connectivity to legacy systems over clouds
Regression Testing	Changed & impacted SaaS/Cloud service features and related APIs/ connectivity	Cloud/SaaS-oriented regression testing inside a cloud	User-centered re-validation on a cloud	End-to-end application system regression over clouds

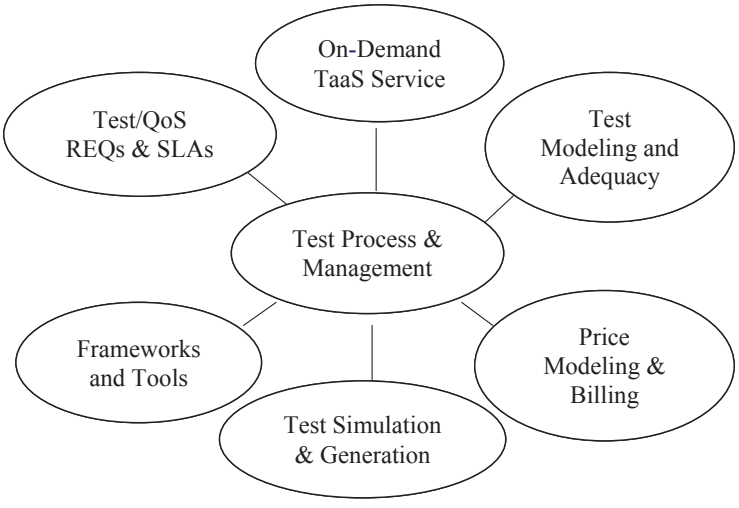

FIGURE 3. THE SCOPE OF CLOUD-BASED SOFTWARE TESTING

3. What are the new features in cloud testing?

Unlike testing conventional web-based software, testing clouds and cloud-based software has several unique testing quality assurance objectives, requirements, and distinct features. This section is dedicated to these subjects. Figure 3 shows the primary contents in the scope of cloud testing.

3.1. New Requirements and Features in Cloud Testing

There are four new requirements and features in cloud testing.

- Cloud-based testing environment – This refers to use a selected cloud infrastructure (or platform) as a base to form a test bed equipped with diverse and scalable computing resources, system infrastructures, and licensed tools, which are allocated using auto-provision based on static/ dynamic requests. Both virtual and physical computing resources can be included and deployed inside.

- Service-level-agreements (SLAs) – In cloud computing, all clouds, SaaS, and applications usually provide diverse services to their end users and customers with well-defined service-level-agreement. Naturally, these agreements will become a part of testing and quality assurance requirements, such as system reliability, availability, security, and performance agreements.

- Price models and service billing – Since utility computing is one of basic concepts and features in cloud computing, so price models and utility billing becomes basic parts and service for testing as a service. In other words, required computing resources and infrastructures (including tools), and testing task services will be charged based on pre-defined cost models and

- Large-scale cloud-based data and traffic simulation - Applying and simulating large-scale online user accesses and traffic data (or messages) in connectivity interfaces is necessary in cloud testing, particularly in system-level function validation and performance testing.

3.2. Testing as a Service (TaaS)

There are several distinct features in cloud testing. One of them is testing as a service (TaaS). This is an innovative concept, and it refers to providing static/ dynamic on-demand testing services in/on/over clouds for the third-parties at any time and all time (365/7/24). One of the primary objectives is to reduce the IT budget of businesses to focus their core businesses by outsource software testing tasks to a third party using TaaS service model [25]. According to Wikipedia, TaaS involves the on-demand test execution of well-defined suites of test material, generally on an outsourced basis. The execution can be performed either on client site or remotely from the outsourced providers test lab/facilities.

According to URL://http://www.tieto.com/, testing as a service (TaaS) was initially introduced as a concept by Tieto in Denmark in 2009, and its solution of TaaS was nominated by IBM for the Software Innovation Award 2009. Now TaaS has received wide attention due to its advantage in its scalable testing environment, cost reduction, utility-based service models, and on-demand testing services.

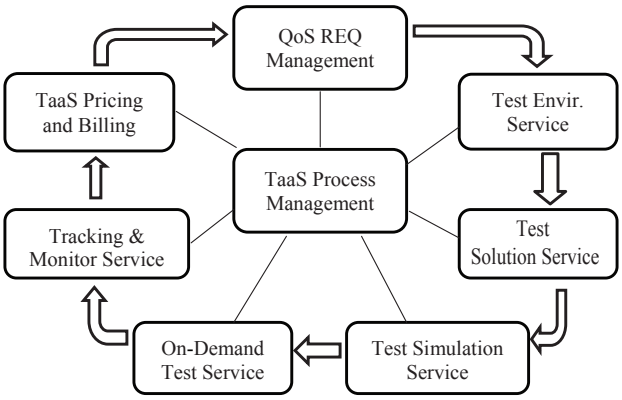

FIGURE 4. THE WORKFLOW OF TAAS

As shown in Figure 4, the work-flow of TaaS includes the following major TaaS service capabilities.

- *TaaS process management*, which offers test project management and process control.

- *QoS requirements management*, which supports book keeping and modeling of software testing and *QoS requirements*, including quality assurance modeling.

- *Test environment service*, which provides on-demand test environment services to establish the required virtual (or physical) cloud-based computing resources and infrastructures, as well as the necessary tools.

- *Test solution service*, which offers diverse systematic testing solutions (such as, test modeling and test methods), and test-ware

generation and management services.

- *Test simulation service*, which establishes on-demand test simulation environments with selected facilitates (such as tools), and supports the necessary test data/message generation.
- *On-demand test service*, which provides on-demand test execution services based on selected schedules and test wares.
- *Tracking and monitor service*, which allows test engineers to track and monitor diverse program behaviors at different levels in/on/over clouds for the testing purpose.
- *TaaS pricing and billing*, which enables TaaS vendors to offer customers with selectable testing service contracts based pre-defined pricing models, and billing service.

3.3. Cloud Testing VS. Conventional Software Testing

Here, we compared the similarities and differences between conventional software testing in cloud testing. Table 2 shows the details in different aspects.

TABLE 2
SOFTWARE TESTING AND CLOUD-BASED SOFTWARE TESTING

	Internet-Based Software Testing (i.e. Distributed/Web-Based System Infrastructure)	Cloud-Based Software Testing
Primary Testing Objectives	- Assure the quality of system functions and performance based on the given specifications - Check usability, compatibility, interoperability.	- Assure the quality of functions and performance of SaaS , Clouds, and applications by leveraging a cloud environment - Assure the quality of cloud elasticity & scalability based a SLA
Testing as a service	- In-house internal software testing as engineering tasks	- Real-time on-demand testing service offered by a third-party - Online testing service based on a pre-defined SLA
Testing and Execution Time	- Offline test execution in a test lab. - Testing a product before its delivery	- On-demand test execution by third-parties; - Online test execution in a public cloud; - Offline test execution in a private cloud
Testing Environment	- A pre-fixed and configured test environment in a test lab. with purchased hardware and/or software	- An open public test environment with diverse computing resources - A scalable private test environment in a test lab.
Testing Costs	- Required hardware costs and software (license) costs - Engineering costs in a test process	- Based on a pre-defined service-level-agreement (SLA) - TaaS and Cloud testing service costs (pay-as-you-test) - Engineering costs in SaaS/Cloud/application vendors
Test Simulation	- Simulated online user access - Simulated online traffic data	- Virtual/online user access simulation - Virtual/online traffic data simulation
Function Validation	- Validating component functions and system functions as well as service features	- SaaS/Cloud service functions, end-to-end application functions - Leveraged functions with legacy systems
Integration Testing	- Function-based integration - Component-based integration - Architecture-based integration - Interface/connection integration	- SaaS-based integration in a cloud - SaaS integration between clouds - Application-oriented end-to-end integration over clouds - Enterprise-oriented application integration between SaaS/Cloud and with legacy systems
Security Testing	Aim to the following targets: - Function-based security features - User privacy - Client/server access security - Process access security - Data/message integrity	Aim to the following targets: - SaaS/Cloud security features, including monitor and measurement - User privacy in diverse web clients - End-to-end application security over clouds - SaaS/Cloud API and connectivity security - Security testing with virtual/real-time tests in a vendor's cloud
Scalability & Performance Testing	- Performed a fixed test environment - Apply simulated user access, ,messages, and test data - Online monitor and evaluation	- Performed in a scalable test environment based on a SLA - Apply both virtual and real-time online test data - Online monitor, validation, and measurement

4. Opportunities, Issues, Challenges, and Needs

To effective perform cloud testing, it is very important to understand the primary issues, potential challenges and needs. This section first discusses the primary issues and challenges, and then summarizes the essential needs in cloud testing. As pointed out by [23], large internet-based solution vendors (like IBM) have identified the priority and cost-reduction opportunities in cloud testing service for large-scale internet-based applications and could-based applications in the near future.

4.1. Issues and Challenges in Cloud Testing

There are a number of issues and challenges in testing clouds and cloud-based software. Here we discuss them from the following four areas.

- *On-demand test environment construction* – How to set up a testing environment systematically (or automatically) for on-demand testing services in a cloud? Although the current cloud technologies support automatic provision of required computing resources for each SaaS (or application) in a cloud, there are no supporting solutions to assist engineers to set up a required test environment in a cloud using a cost-effective way. It is necessary to provide an on-demand test environment for TaaS customers. To do this, TaaS vendors need to provide a systematic solution to establish a required test environment based on the user's selection. In addition, engineers also found that there is a lack of cost-effective solutions for them to easily leverage their cloud-based applications (or SaaS) in a cloud with the existing test tools because most of them are not cloud-enabled.

- *Scalability and performance testing* - Although many published papers discuss system performance testing and scalability evaluation in the past two decades, most of them address issues and solutions in conventional distributed software or web-based software systems. According to our recent literature survey on this subject, most existing papers focus on scalability evaluation metrics and frameworks for parallel and distributed systems [19][20][21] [22]. Since these systems are set up with pre-configured system resources and infrastructures, performance testing and scalability evaluation are usually conducted in a static and pre-fixed system environment (such as a test lab.), so the existing evaluation metrics, frameworks, and solutions did not consider the special features in cloud testing, such as dynamic scalability, scalable testing environments, SLA-based requirements, and cost-models.

- *Testing security and measurement in clouds* – Security testing has becoming a hot research subject with many open questions in current software testing community. Since security becomes a major concern inside clouds and security services become a necessary part in modern SaaS and cloud technology, engineers must deal the issues and challenges in security validation and quality assurance for SaaS and clouds. Here are some related issues and challenges:

  - How can we assure the security of cloud-based application processes and business data inside a third-party cloud infrastructure [17]?
  - What are the QoS standards for security-oriented quality assurance for end-to-end application process and related business data in/on/over clouds?
  - What are the test models, test adequacy, test techniques and tools for security testing for end-end applications in/on/over clouds?
  - How can we assure and assess user privacy in a cloud infrastructure [18]?

- *Integration testing in clouds* - Although we have seen numerous published research papers addressing software integration testing issues and strategies, not much research results have been applied in the real engineering practice. One of the major reasons is the existing software and components are developed without enabling technology and solution to support and facilitate systematic software integration. In a cloud infrastructure, engineers must deal with integration of different SaaS and applications in/over clouds in a black-box view based on their provided APIs and connectivity protocols. This could cause a lot of extra integration costs and difficulties due to the following issues.

  - There is a lack of well-defined validation methods and quality assurance standards to address the connectivity protocols, interaction interfaces, and service APIs provided by SaaS and clouds APIs.

- There is a lack of cost-effective integration solutions and framework to facilitate software application integration and assembly inside clouds and over clouds.

- *On-demand testing issues and challenges* - In TaaS, software testing services must be controlled and managed based on on-demand testing requests. This kind of new testing service model raised several issues and challenges.

  - What is the automatic test process for TaaS to support on-demand automation testing?
  - What are the well-defined cost models for testing as a service?
  - How can engineers use a systematic approach to model and define QoS requirements?
  - What are the intelligent approaches to coping with the failures of software testing scripts/ test cases in an on-demand testing process?

- *Regression testing issues and challenges* – Supporting on-demand software validation in clouds must address the regression testing issues and challenges caused by software changes and bug-fixing. However, most existing research in software regression testing pays most attention to re-test a specific software version in a pre-configured test environment. The multi-tenancy feature of clouds may cause the difficulty to apply the exsiting research work in cloud testing, specially for on-demand software regression testing service whenever software changes. In addition, we also lack of dynamic software validation methods and solutions to address the dynamic features of SaaS and clouds, for example automatic provisioned/de-provisioned features.

4.2. Major Needs in Cloud Testing

There are a number of major needs in cloud testing. They are discussed below.

Need #1: Adequate test models and criteria

To effectively support cloud testing, engineers need new adequate test models and criteria in the following areas.

- Scalability models for SaaS/Cloud-based Applications - Engineers need well-defined adaptive test models and evaluation metrics for scalability and performance testing in clouds to validate and measure dynamic system scalability (such as scale-up and scale-down) and system performance (such as improvement and degradation). These models and metrics must address scalable computing resources, dynamic system loads, and pre-defined economic sales (cost/price models).

- Adequate integration models and criteria – To address software integration issues in cloud testing, engineers need adequate test models and criteria addressing three types of integration in cloud testing:

  - Cloud-based connectivity protocols and APIs crossing clouds
  - SaaS (or application) APIs and interactions to legacy systems outside clouds
  - End-to-end application integration crossing clouds

Need #2: TaaS test processes and QoS standards

Today's commercial SaaS and clouds provide different types of Service Level Agreement (SLA) for users. However, both vendors and users need well-defined testing and quality assurance standards as a theoretic base to establish fair and sound service level agreements between them. Here are some specific examples.

- Although application system and data security should listed as a part of requirements for SaaS and clouds, today's cloud technologies and major players only list the security requirements for cloud infrastructure. One major reason is the lack of testing and QoS standards that address cloud and SaaS security in different aspects including, application data security, end-to-end transaction security, business process security, and user privacy.

- Since TaaS is a new concept and service model for software testing, there is a lack of well-defined TaaS processes and QoS standards for on-demand testing services, for example, price models.

Need #3: Innovative test methods and solutions

The new features and new requirements of cloud-based applications and SaaS bring some demands on new test methods and solutions.

- *Continuous validation and regression testing solutions* – Since high system availability is very important to SaaS and cloud-based applications, engineers need automatic re-testing techniques to address the multi-tenancy feature of clouds whenever software are changed for bug-fixing or feature improvement.

- *New automatic test solutions for cloud interoperability* – Because both clouds and SaaS provides their connectivity protocols and APIs, this requires engineers to assure the quality of interoperability of cloud-based applications crossing different clouds in connectivity protocols, firewalls, interactions between SaaS and legacy systems.

- *Innovative test technologies for cloud compatibility testing* – Cloud-based applications and SaaS must support global online users to access the provided services using diverse client platforms, browsers, and technologies, this suggests that vendors need new effective test technologies to support the validation of application compatibility on different platforms, client technologies, and browsers.

Need #4: Innovative dynamic test platforms and tools

Cloud testing requires large scale real-time test loads in a scalable web-based distributed environment. This suggests the need of several test tools and solutions. ***One of them*** is a powerful test simulator, which provides large-scale web-based test simulation and data generation in a cloud using virtual and physical computing resources. To effectively use the existing performance solutions, it is clear that certain flexible interfaces and gateways are needed in the simulator to connect to existing performance test tools. The ***next*** is an innovative integration test solution that supports easy and seamless integration between SaaS and applications crossing clouds. This implies that certain standard API-based and connectivity-enabled test frameworks are needed to support the integration over clouds. ***The third*** is the cloud-based performance and scalability solutions that support engineers validate non-function requirements for SaaS and cloud-based applications at different levels to assure their performance and scalability based on the given SLAs and certain economic scales (or cost models). ***Furthermore,*** an innovative end-to-end program tracking solution is needed to support software testing, bug-fixing, and maintenance of cloud-based programs at different levels. This solution enables engineers to understand, test, and monitor end-to-end application processes, transactions, service functions, and interactions between SaaS and clouds.

TABLE 3

A COMPARISON VIEW ABOUT CLOUD TESTING PODUCTS, SOLUTIONS AND SERVICES FROM FOUR MAJOR PLAYERS

	PushtoTest http://www.pushtotest.com/	Cloud Testing http://www.cloudtesting.com/	SOASTA http://www.soasta.com/	iTKO http://www.itko.com/
Testing Products	- Test Maker	- Cross browser testing - Website archiving - Function testing	CloudTest™ supports test recording, editing, assembly, monitoring, and integrated Analytics	LISA product suite: LISA VirtualizeTM LISA Test LISA Validate LISA Pathfinder
Test Services	- PushTotest, TestOnDemand	- Function test service - Cross browser testing - Website archiving service	- CloudTest On-Demand - CloudTest Appliances	Education and consulting service on cloud-based application testing
Function Testing	Web-Based, RIA-based, and SOA-based function testing	Script-based function testing support for testers, developers, and website managers	Visual and UI-based function testing	- Automatic GUI testing, codeless testing, continuous and event-based validation
Test Development	- Record/playback, unit test, - object/component oriented test development	- Script-based test development - Web-based record/replay	- Test editing and test assembly with tools - Visual web-based record, capture, filtering and automated test clip creation	- Virtualized and codeless test development - Build executable tests by integrating with existing test repositories.

Test Monitoring and Virtualization	- Web 2.0, SOA, RIA, Ajax, Flex Flash Applications - BPM service monitoring - Web REST service	- Crossing browser monitoring - Script-based test monitoring - Project status monitoring - Script report and monitor	- Agent-less approach for open network protocols - Agent-based approach for connections inside a firewall - Resource monitoring - Performance monitoring	- Continuous validation monitor - End-to-end transparency and monitor of application behaviors at different levels
Test Methodology and Solutions	- Agile Test-First Methodology - Script-based test development - Record and replay	- Script-based execution - Record and replay - Script-based test development	- Real-time playback - Record and replay - Visual test creation, edition, and assembly	- Continuous and event-based validation - Complete and collaborative test
Interoperability and Web Browsers & Technology	HTML, Ajax, Web 2.0, Flex, and Flash	IE (version 6-8), Firefox Apple Safari, Google Chrome, and Opera	Internet Explorer, Firefox, Safari, HTML, Ajax, and JSON,	No details
Scripting	- Support Java, Jython, Ruby and dynamic scripting languages	- Create, edit, execution, snippet of Selenium scripts - Upload/import/export scripts	No detailed information available except Selenium	Code-less test generation from users' perspectives
Test Execution Support	- Single and current test execution threads - Script-based test execution	- Scheduled and manual - Grouped/multi browsers - Grouped scripting and their test execution control	- Scheduled and manual test execution control - Visualized test running & control	- Visual scheduled test execution - Event-based test execution and regression
Connectivity and API Support	Ajax, Flex, Flash, SOAP and REST, XML-RPC, HTTP(s), ESB/Message Queues	- Script-Based Test API - HTTP(S)	- SOAP, REST, HTTP(S) - SSH, SNMP, RMI	Integration to most J2EE servers, integration suites, and ESBs
Service costs	- Pay as you test - Monthly subscription	- Pay as you test ($75 for 500 tests)	- Pay as you test	- Pay as you test

5. CURRENT TECHNOLOGIES, SOLUTIONS, AND MAJOR PLAYERS

Since 2008, testing as a service (TaaS) and cloud testing become hot topics in industry. IBM and Hewlett-Packard have jumped into the market for cloud testing in clouds. Meanwhile, there is a handful of startups already offer their solutions on-premises testing on clouds. Based on our recent survey of related industry products and services, we summaries several leading technologies and solutions by major players here. A comparative view is given in Table 3.

- ***SOASTA*** – As a precursor on cloud testing market, SOASTA has its unique cloud testing product family (known as SOASTA CloudTest™) to support common web application tests in performance and load testing, function testing, and UI testing either inside a firewall or inside "The Cloud". Their on-demand testing service (as a resident in the Cloud) offers users with a scalable cloud testing environment at affordable costs for testing service. In addition, SOASTA's CloudTest-Appliance, allows customers perform affordable load testing and end-to-end performance evaluation using scalable system appliances inside a firewall. According to its website and white papers, SOASTA provides a management console with powerful browser recorder and script editor, which allows testers to edit, assembly and group test scripts easily with a visual interface. In addition, SOASTA supports test engineers to validate large-scale web applications and services with many web pages, messages and events. These web applications may support tens or hundreds of thousands of users, and have a variety of connectivity protocol. Such as HTML, SOAP, REST, HTTP, Ajax and so on. Although there is no price list posted on the website for on-demand service testing, but customers can buy CloudTest Appliance or On-Demand version.

- ***iTKO*** – As one major player in cloud testing service, iTKO provides its customers with a LISA product suite. It focuses on development and testing service for cloud applications. iTKO's LISATM Test is an integrated and collaborative automated testing solution designed for Cloud

applications and other distributed application architectures that leverage SOA, BPM, integration suites, and ESBs. It provides testers a codeless testing environment allows QA and engineers to develop tests for unit testing, function testing, integration, regression, as well as performance and load validation. According to the posted information, LISA TM Virtualize eliminates system dependency constraints by "virtualizing" or capturing and modeling since it is able to simulate a targeted system's dynamic behavior, performance and data so that it reacts and responds the same as the live system. Using LISA Virtualize, test and development teams are able to concurrently perform tests in 24/7/365 to shorten their test process cycles. As one of important solutions of iTKO, LISATM Validate provides continuous or event-based end-to-end function and performance validation for components, servers, and SaaSs over a cloud infrastructure to reduce the risks and unintended consequences of change. iTKO's LISATMPathfinder offers the visualization for cloud-based applications so that end-to-end business application processes and system behaviors can be monitored and virtualized. This will removes critical accessibility and capacity constraints, while dramatically reducing the impact of complexity and change in the Cloud. Comparing with the products from other vendors, LISA's virtualization and validation solutions are essential for realizing elastic Cloud Application development and test environments.

- ***Cloud Testing*** – Cloud Testing develops cloud-based testing solutions focusing on large-scale web-based application testing by leveraging with cloud infrastructures. It offers different web-based testing crossing different browsers, including IE, Firefox, Opera, Chrome, and Sadari. Cloud Testing allows engineers to create and maintain test scripts manually or to use the record-and-replay approach. Cloud Testing offers three types of testing services to allow developers, testers and website managers to automate and speed up the testing and archiving of their websites using real browsers from the cloud. These include: a) cross browser testing, b) website archiving, and c) function testing. According to Cloud Testing, it provide and delivers its services in a SaaS (Software as a Service) model, so its customers have no need to invest in computing hardware, software or consultancy before software testing. With Cloud Testing's solutions, customers can focus on their work in web-based application development, testing and execution.

- ***Push To Test*** – This is a small startup business focusing on testing services for Grid-based and Rich Internet applications (using Ajax, Flex, Flash) and SOA-based application systems. Its major product is TestMaker, which is designed to support the validation of distributed web-based applications with test scripts developed in different scripting languages, such as Java, Jython, and Ruby. The current version of TestMaker focuses on function testing and load testing. According to PushToTest, its TestMaker works with a number of open-source testing tools, such as SoapUI, Selenium, HTMLUnit, Glassbox, SpikeSource, and Appcelerator. Now, PushToTest is moving to support cloud testing by offering its OnDemand cloud testing solution based on third-party cloud technology and environment, such as Amzon EC2. According to PushToTest, it also provides different monitoring services to customers through a number of connectivity protocols, including Ajax, Flex, Flash, SOAP and REST. In addition, it offers protocol handlers of XML-RPC, ESB/Message Queues, and HTTP.

Clearly, these vendors are the pioneer in cloud testing. There is still a long way to go to address the open issues, needs, and challenges in cloud testing because none of them has any solutions to cope with security testing, automatic validation, dynamic integration, and scalability evaluation, as well as quality assurance standards and test adequacy for cloud-based applications and infrastructures.

6. EXISTING RESEARCH WORK

Since 2008, there are many published papers discussed grid-based and cloud-based software infrastructure, design, management, technologies, and standards. However, there is a very few of articles discussing cloud testing and cloud-based application testing. Although there are a number of vendors offering cloud testing services to support cloud-based applications, there is a lack of clear understanding about cloud testing in terms of concepts, issues, challenges, and needs. This section briefly reviews the published papers relating to software testing as service and cloud testing.

- *Test modeling for clouds and cloud-based applications* - T. Vengattaraman et al. in [2]

propose their initial work on modeling of cloud-based application environment for software testing by focusing On-Premises Applications over clouds. Its major objective is to present the relationships between different application services over clouds and external consumer services. The details about how to use this model in cloud testing are not addressed yet. W.K. Chan et al. in [5] present a formal model to present clouds and their associated services using a graph model, known as cloud graph. Cloud computation is represented as a set of paths in a subgraph of the cloud such that every edge contains a predicate that is evaluated to be true. As indicated by W. K. Chan, there are no any existing testing criteria for cloud applications even though some testing criteria for service-related systems have been proposed [8].Our recent literature survey on cloud software testing has confirmed this.

- *Software testing as a service (STaaS)* – Leo van der Aalst in [12] provides his STaaS definition, process, infrastructure and some experience results. In [5], Leah Muthoni Riungu et al. reports their recent study on software testing as online services from practitioners in the industry. The paper summarizes the findings based on their Interviews with software testing providers and customers. The underlying research question was: "What conditions influence software testing as an online service?" Based on the received responses, they discuss the requirements, benefits, challenges, and some research issues from the perspectives of online business vendors and practitioners. Yang Yang at al. [11] discussed that software testing can be conceptualized as a service rather than being viewed as a sequential line of responsibility in software development. In their view, TaaS has two key aspects: (1) a service to developers, and (2) a service to end users. Their paper discusses software testing as a service from software quality assurance perspectives. George Candea, et al [7] discusses three types of TaaS services. These include (1) a public certification service, which independently assesses the reliability, safety, and security of software; (2) a "home edition" on-demand testing service for consumers before product deployment; and (3) a "programmer's sidekick" enabling developers to thoroughly and promptly test a developed program with minimal upfront resource investment. Recently, IBM reports their experience and benefits in cloud testing by leveraging cloud software and environments [14].

- *Cloud testing environment and tools* - Liviu Ciortea et al. in [13] introduce Cloud9, a cloud-based testing service that promises to make high-quality testing fast, cheap, and practical. Cloud9 is the first parallel symbolic execution engine to run on large shared- clusters of computers, and its test harness uses the aggregate memory and CPU resources based on compute utilities like Amazon EC2. The paper reports their initial prototype results. In addition, some initial cloud-based test experiments are reported.

7. Conclusion and Future Work

Cloud testing is becoming a hot research topic in cloud computing and software engineering community. As the advance of cloud technology and testing as services, more research work must be done to address the open issues and challenges in cloud testing and TaaS. More innovative testing techniques and solutions, and QoS standards are needed to support on-demand testing services in a scalable cloud infrastructure. This paper provides a comprehensive review and tutorial on cloud testing by discussing the related concepts, issues, and challenges. The major contributions of this paper include its insightful discussion about cloud testing in terms of its special requirements, benefits, and features as well as the comparison with conventional testing. Moreover, cloud testing opportunities, current major players, and existing research work are reviewed.

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