A Survey and Taxonomy of Cloud Migration

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***Abstract*—Cloud computing has certainly gained attention and skyrocketed in the technical and economic world because of the appealing features. With decades of development there are lots of on-premises applications and systems in use. Consequently, the demand of migrating on-premises applications and systems to the cloud computing is gigantic. Thus, the cloud migration is not systematically reviewed with a proper taxonomy due to the variety of cloud computing architecture and the complexity of applications and systems. This paper surveys the cloud computing architectures and cloud migration decision frameworks by both the industry and the academia. Then, it proposes cloud migration taxonomy for a clear understanding of related approaches. Finally, it addresses the future challenges and direction as well.**

Keywords—cloud migration; survey; taxonomy; cloud computing

I. Introduction

National Institute of Standards and Technology (NIST) defines cloud computing as a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction [1]. Cloud computing encapsulates the delivery of computing resources as a service. A service is a provider-to-client interaction that creates and captures value while sharing risks [2]. The advancement of cloud computing is therefore intrinsic to the development of the next generation of internet. This paper considers the current vary technologies of cloud computing and the migration to cloud computing. In particular we present survey and taxonomy of the cloud migration decision approaches and the cloud migration practices.

Cloud Computing has since developed into a significant and well defined domain. The most accepted description of the general characteristics of cloud computing comes from the NIST and other contributors [1][3]. It defines a concise set of properties which define a cloud computing system: 1) *On-demand Self Service*: A consumer is able to provision resources as needed without the need for human interaction. 2) *Broad Access*: Capabilities of a Cloud are accessed through standardized mechanisms and protocols. 3) *Resource Pooling*: The Cloud provider's resources are pooled into a shared resource which is allocated to consumers on demand. 4) *Rapid Elasticity*: Resources can be quickly provisioned and released to allow consumers to scale out and in as required. 5) *Measured Service*: Cloud systems automatically measure a consumer's use of resources allowing usage to be monitored, controlled and reported.

The NIST standard also defines three layers within the cloud stack: *Software as a Service (SaaS)*, *Platform as a Service (PaaS)* and *Infrastructure as a Service (IaaS)*. SaaS is defined as the delivery of an application, typically a web application, on-demand via the Internet. PaaS is the delivery of a software platform and associated development tools via a service model. IaaS is the provisioning of computer resources including virtual machines (VMs), storage, networking and other resources via a service model.

The NIST cloud computing reference architecture defines five major actors: *Cloud Consumer, Cloud Provider, Cloud Carrier, Cloud Auditor* and *Cloud Broker*. Each actor is a person or an organization that participates in a transaction or process and/or performs tasks in cloud computing [4]. ITU-T proposes three cloud ecosystem actors: *Cloud Service User (CSU)* is a person or organization that consumes delivered cloud services; *Cloud Service Provider (CSP)* is an organization that provides and maintains delivered cloud services; *Cloud Service Partner (CSN) is* a person or organization that provides support to the building of the service offer of a cloud service provider [5]. In many other reference models there are only three actors: *Cloud Service Consumer*, *Cloud Service Provider* and *Cloud Service Developer* [6].

Today is the booming phase of Cloud Computing. The traditional on-premises IT systems, applications will migrate to the Cloud Computing environment. And the key role or actor is *Cloud Consumer* or *Cloud Service User*. For the migration to cloud computing, Kundra, the U.S. Chief Information Officer, presented Decision Framework for Cloud Migration in [7]. The framework includes three steps: 1) Selecting services to move to the cloud; 2) Provisioning cloud services effectively; 3) Managing services rather than assets.

The objective of this paper is threefold. First, we summarize previous reviews and taxonomies of cloud computing. Second, we survey the cloud migration decision making approaches and sort out considerations of cloud migration. Finally we survey the constituent technologies, consider the problems within these areas and suggest the paths for cloud migration. The remainder of this paper is organized as follows: In Section II, we present the taxonomy of cloud

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computing. In Section III, we briefly introduce cloud computing migration decision framework and related works. Next, in Section IV we propose a taxonomy of cloud migration from the cloud consumer's angle, and review how each approach has been addressed in related research. Finally, in Section V we propose the research directions basing on our survey and taxonomy.

II. TAXONOMY OF CLOUD COMPUTING

There are many other existent cloud architecture reference models. Cloud architecture [8] is the structure of a cloud solution that uses Internet-accessible on-demand services. The term also defines the structure of cloud services and cloud components, management, security, operation, and monitoring. Cloud computing is getting popular and IT giants such as Google, Amazon, Microsoft, IBM have started their cloud computing services. However, current cloud implementations are often isolated from each other [9].

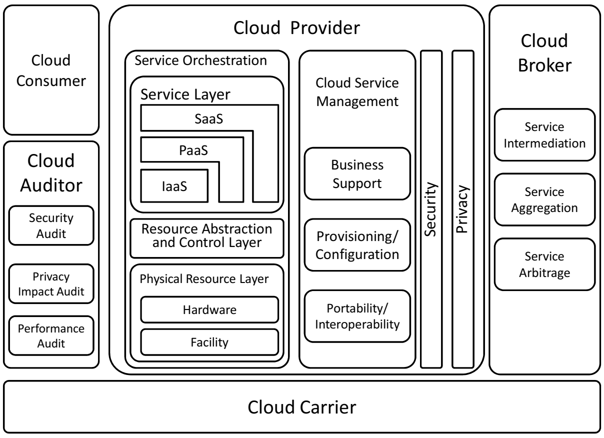

Fig. 1. Cloud computing architecture conceptual reference model

A cloud architecture reference model is an abstraction of cloud computing concepts and relationships [6]. It can be used to create guidelines to help apply those concepts. Groups such as the Distributed Management Task Force, IETF, Cloud Security Alliance, and Open Security Architecture are developing cloud reference models to help adopting cloud technologies. The NIST cloud computing reference architecture defines five major actors: *Cloud Consumer, Cloud Provider, Cloud Carrier, Cloud Auditor* and *Cloud Broker*. Fig. 1 presents the cloud computing reference architecture defined in [1]. In many other reference models there are only three actors: *Cloud Service Consumer*, *Cloud Service Provider* and *Cloud Service Developer*. As depicted in [6] there are eleven cloud reference architecture models proposed by well-known cloud organization, providers and agencies including six general reference models and five reference models focusing on specific application requirements. The six general reference models are: 1) Distributed Management Task Force (DMTF): Cloud Service Reference Architecture; 2) Cloud Computing Use Case Discussion Group: a taxonomy for cloud computing; 3) IBM: Cloud Reference Architecture; 4) Cloud Security Alliance: Cloud Reference Model; 5) Cisco Cloud Reference Architecture Framework; 6) IETF: Cloud Reference Framework. The five reference models focusing on specific application requirements are: 1) Open Security Architecture: Secure Architecture Models; 2) GSA: FCCI (Federal Cloud Computing Initiative); 3) Juniper Networks: Cloud-ready Data Center Reference Architecture; 4) SNIA standard: Cloud Data Management Interface; 5) Elastra: A Cloud Technology Reference Model for Enterprise Clouds.

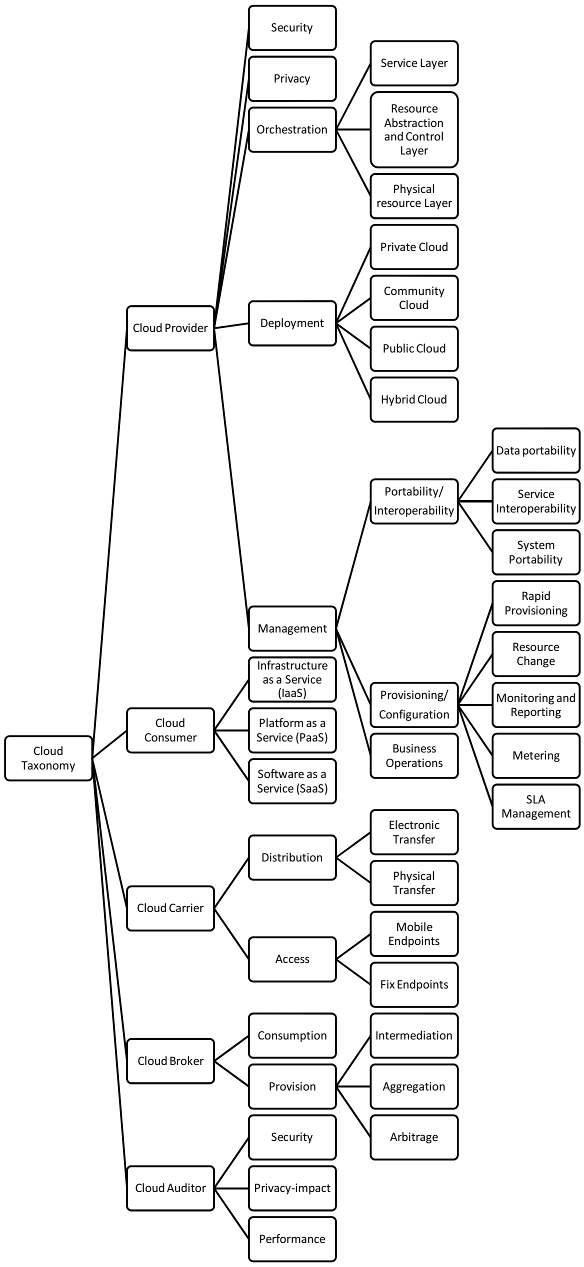

Fig. 2. Cloud Computing Taxonomy

As defined in [4] a taxonomy of Cloud Computing is depicted in Fig. 2. It corresponds with the cloud computing reference architecture in Fig. 1. A four-level taxonomy is used to describe the key concepts about cloud computing. Besides the root *Cloud Taxonomy* there are four levels: 1) *Role*, which indicates a set of obligations and behaviors as conceptualized by the associated actors in the context of cloud computing; 2) *Activity*, which entails the general behaviors or tasks associated to a specific role; 3) *Component*, which refer to the specific processes, actions, or tasks that must be performed to meet the objective of a specific activity; 4) *Sub-component*, which present a modular part of a component. Level 1 consists of five major actors: *Cloud Consumer, Cloud Provider, Cloud Carrier, Cloud Auditor* and *Cloud Broker*. Each actor plays a role and performs a set of activities and functions. *Cloud Consumer* is defined as *person or organization that maintains a business relationship with, and uses services from, Cloud Providers*. Cloud consumers are categorized by service into three groups: SaaS, PaaS and IaaS. HaaS (Hardware as a Service) is introduced by Rimal et al. [10]. There are also finer granular, or more aggressive, categorizations treat Everything (Anything) as a Service (XaaS). So many new types such as *Storage as a Service,* Database as a Service, Information as a Service, Process as a Service and etc emerged. A well-known collection includes more than twenty of XaaS [11]: Architecture as a Service (AaaS), Business as a Service (BaaS), Computing as a Service (CaaS), CRM as a Service (CRMaaS), Data as a Service (DaaS), Database as a Service (DBaaS), Ethernet as a Service (EaaS), Frameworks as a Service (FaaS), Globalization or Governance as a Service (GaaS), Hardware as a Service (HaaS), Information as a Service (IMaaS), Infrastructure or Integration as a Service (IaaS), Identity as a Service (IDaaS), Lending as a Service (LaaS), Mashups as a Service (MaaS), Organization or Operations as a Service (OaaS), Software or Storage as a Service (SaaS), Platform as a Service (PaaS), Technology or Testing as a Service (TaaS), Voice as a Service (VaaS), Blog as a Service (BlaaS). Höfer et al. [12] summarize Storage as a Service (StaaS), Database as a Service (DbaaS), Information as a Service (InaaS), Business Process as a service (BPaaS), Integration as a Service (InaaS), Security as a Service (SeaaS), Management/Governance as a Service (MGaaS), Testing as a Service (TaaS), IaaS, PaaS, SaaS and their typical commercial vendors. In fact, as the definition of NIST all other XaaS can be categorized into the triple services: SaaS, PaaS and IaaS.

There are also some cloud computing taxonomies. Youseff et al. [13] propose a unified ontology for cloud computing. It presents a summary of cloud computing components, with a classification of these components, and their relationships. Leavitt et al. [14] present the whole cloud scenario with advantages and disadvantages, explaining the adoption of cloud by companies around the world and classifying cloud computing environments into four types.

III. Decision of Cloud Migration

The vision of cloud computing is attractive. But, current application or business systems are based on traditional on-premises architecture. And, the variety of cloud computing incurs broad scope and size of the cloud migration. It requires a meaningful shift in the thought of IT. The traditional thought of IT is an investment in locally owned and operated applications, servers, and networks. Facing cloud computing the new terms of services commoditized computing resources, agile capacity provisioning tools and so on. The new technologies have a broad impact across the entire IT service lifecycle [15]. Fig. 3 depicts the compare of on-premises and cloud computing based application/system. The cloud migration is the application/ system transforming from on-premises to cloud computing.

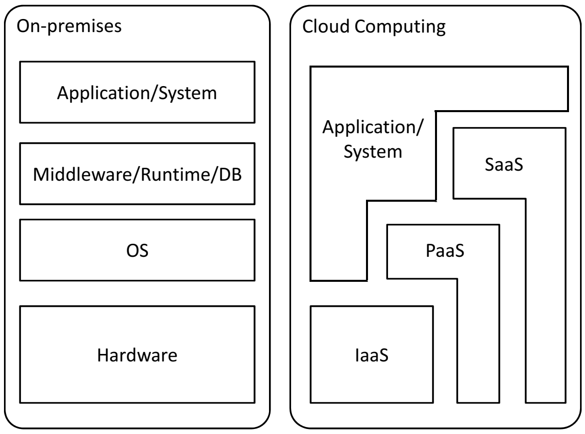

Fig. 3. On-premsises and cloud computing applciaton/system

There are many research efforts on the cloud migration decision making. Fig. 4 shows the cloud migration decision framework addressed in [15]. Generally the framework can be separated as three steps: 1) Selecting services to move to the cloud; 2) Provisioning cloud services effectively; 3) Managing services rather than assets. Andrikopoulos et al. studied migrating applications to cloud computing in [16]. The key concerns identified include: 1) The impact of the logical and physical distribution of the migrated application. 2) Elasticity mechanisms can be used. 3) Multi-tenancy. 4) The calculation of the cost of migrating and operating. 5) The Quality of Service levels and security affection. Andrikopoulos et al. [17] indicates the key decision that the system should support: 1) How to distribute the application across service providers. Different application topologies based on the various identified migration types should be considered. 2) How to select a cloud service provider and offering that fits the application needs in terms of cost, performance, compliance and security concerns. 3) What are the requirements of the application in terms of multi-tenancy. 4) Which is the elasticity strategy that the application needs to implement. Besides, following tasks are also identified: *Work Load Profiling, Compliance Assurance, Identification of Acceptable QoS Levels, Cost Analysis* and *Effort Estimation*. In [18] cost modeling, benefits and risks assessment matrixes are used to help the decision making. Besides the financial and technical benefits stemming from the use of computing, storage and networking resources in public cloud offerings, some improvements arise from the organizational point of view, mainly regarding an increased agility and an enhanced division of labor [3] [18]. The ability to develop, test, and scale applications in environments with volatile and unpredictable demand is a very interesting feature not only for rapidly evolving start-up companies [18] but also for companies pursuing innovative projects or seeking to react to sudden changes in the business environment. However, these benefits can easily be counterbalanced when security and privacy issues come into play and when interdependencies with other pre-existing applications gain in relevance and strength [19]. Additionally, despite the potential immediate cost reductions that can be achieved by running a single application or component in a cloud environment [20], the cloud-based provision might have negative effects on the overall lifetime cost of the higher-order enterprise system.

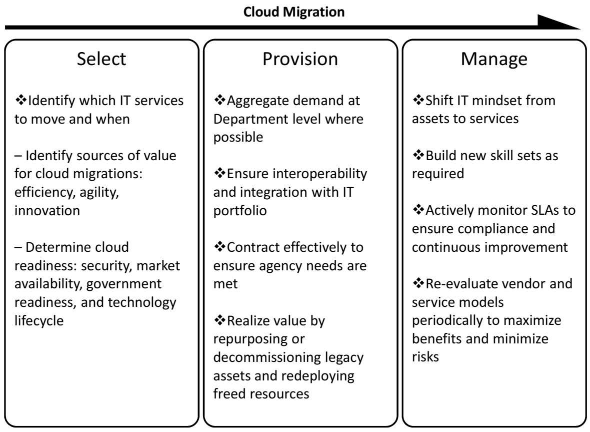

Fig. 4. Cloud migration decision framework

More specifically, there are technical, economic, and compliance related factors that have to be considered when moving an enterprise application to a cloud environment. From a technical standpoint, performance requirements of an application, availability, traceability of errors, data and system lock-in problems, as well as interoperability issues have to be considered [18]. The approach is a multi-dimensional statistical evaluation; enterprise applications are evaluated in three dimensions: 1) Business value, 2) Technical fitment, 3) Risk exposure. A case study in [21] illustrates the potential benefits and risks associated with the migration of an IT from an on-premises data center to Amazon EC2. It comprises of: 1) Identify key stakeholders; 2) Identify changes; 3) Identify the likely consequences; 4) Analyze changes within the wider context; 5) Determining whether the stakeholder will perceive the change. The results of the case study fieldwork are: Infrastructure Costs, Support and Maintenance, Stakeholder Impact Analysis, Benefits, Risks.

Generally, the migration decision is not only a technical one. It is more significantly impacted by the organizational factors.

IV. TAXONOMY OF CLOUD MIGRATION

Cloud delivers computing resources as services. And the cloud migration capability can be delivered as Cloud Migration as a Service (CMaaS). In fact the current cloud migration practices are labor intensive the error prone due to the complexity of the applications. As discussed in previous section the decision making of cloud migration is basing on multi-dimension. From both technology and business angles we can give a taxonomy of cloud migration. As discussed in [22] there are many virtualization technologies to support different cloud services including server, desktop, storage, network, application, infrastructure and resource. The cloud migration is to adopt and utilize these technologies.

Fig. 5 depicts the mapping of three layers of cloud computing environment and corresponding traditional on-premises systems. The target of cloud migration is cloud computing environment and usually the source is on-premises systems. The migration between two different cloud computing service vendors is also realistic especially to avoid the service vendor lock-in.

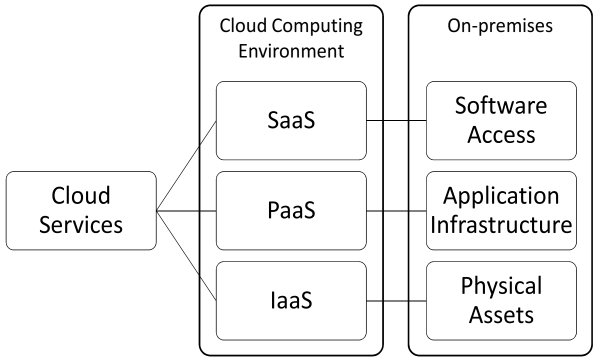

Fig. 5. Cloud computing and on-premises systems

Generally speaking, cloud migration transforms legacy applications into the services paradigm at both business and technical levels. Cloud service allows systems to remain mostly invariable while exposing functionalities to a large number of customers through interfaces. However, not all organizations start from the same initial situation in terms of the maturity of an application or the organization at both the technical and business aspects. Likewise, the target situation of each company or application after a migration can differ as well. Based on all above aspects, specific and personalized strategies should be applied for each specific application or organization. Furthermore, complete this analysis would provide the organizations with a clear view of migration. Before undertaking the actual cloud migration, the estimated human effort, time, cost or resources required are well estimated and established.

Andrikopoulos et al. classify the application moving to cloud computing into four types in [16]: 1) Replace component(s) with Cloud offerings. 2) Partially migrate some of the application functionality to the Cloud. 3) Migrate the whole software stack of the application to the Cloud. 4) Cloudify the application: a complete migration of the application takes place. A key issue is to adapt the application to operate in mixed environment. The three layers pattern (presentation, business logic and data) based application migration in [23] introduces a set of architectural components can be migrated to the Cloud, and different deployment can be used. Babar et al. present migration to cloud case study in [24]. Hackystat framework was migrated from a client-server web application to a service-oriented architecture following Representational State Transfer (REST) design principles. The objective was to modify Hackystat as an SaaS model to be deployed on an IaaS cloud. Clark et al. [25] study in live migration of entire OS instances. In their implementation they addressed several of the issues and trade-offs involved in live local area migration. These issues include: 1) Minimize the downtime; 2) Minimize the total migration time; 3) Avoid unnecessarily disrupt active services through resource contention with the migrating OS. Yang et al. [26] propose an approach to build a cloud IaaS environment, which integrates KVM and OpenNebula open sources to provide a cloud virtual environment for users to reduce the complexity of accessing cloud resources. Hines et al. propose a live migration approach is "Post-Copy Live Migration of Virtual Machines" [27] to reduce the total migration time. Lai et al. [28] propose a cloud service architecture named as dual migration. The dual migration architecture keeps monitor the location of a user and migrates the contents what the user might need on to the closest server for the current location of the user. Al-Kiswany et al. propose a migration service for cross-datacenter transfer and instantiation of groups of virtual machine images that comprise an application-level solution [29]. It provides an approach to avoid service provider lock-in.

The following paragraphs summarize the cloud migration scenarios and present taxonomy of cloud migration. The benefits and risks were categorized as organizational, legal, security, technical or financial [18]. As discussed in previous section the decision of migration can be made by following a certain process will not address here and we only discuss migration approaches in this section.

A. Migrate Physical Assets to IaaS

According to the definition of NIST IaaS is to provision traditional physical assets including processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run operating systems and applications without managing or controlling the underlying cloud infrastructure. The infrastructure usually shared and thus cost reduced or pay by usage, self-scaling. The advantages include lower capital expenditure on hardware reduced return on invest risk, low barriers to entry, streamlined and automated scaling.

1) Physical machine to virtual machine

a) Approach: Capture image and convert to target format. This type of migration usually need the capture the image from source physical machine, adjust the image and deploy it in the IaaS environment.

b) Examples: IBM Smart Business Development and Test on the IBM Cloud. Amazon Elastic Compute Cloud (Amazon EC2), Amazon CloudFront, Mosso cloud sits and Skytap virtual lab service.

2) Physical devices to device services

a) Apporaches: Adopt cloud based device services with internet access replace the local physical devices.

b) Examples: Print On Demand (POD) service is an example of organizations that can benefit from IaaS. Service consumer is not necessarily to purchase print devices and only need to pay as you go. Amazon EC2 CUDA services provide GPU hardware for GPU based parallel programming.

B. Migrate Application Infrastructure to PaaS

PaaS has the capability to adopt consumer-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider without managing or controlling the underlying cloud infrastructure including network, servers, operating systems, or storage. It provides a development platform with a set of services to assist application design, development, testing, deployment, monitoring, hosting on the cloud.

1) Migrate OS to cloud

a) Apporaches: Utilize cloud based OS with proper hardware resource.

b) Examples: IBM, Amazon and most other hosts provider.

2) Migrate deployment to cloud

a) Apporaches: Deploy the software nodes to cloud computing environment with the given policy/topology.

b) Examples: IBM SCE, Amazion EC2.

3) Migrate runtime environment to cloud

a) Apporaches: Use the cloud based runtime environment. The software componet can be seamless redistribute to the cloud supporting the same type/version of runtime.

b) Examples: .NET framework by Microsoft and Java runtime from Oracle, Python, Perl, Ruby, TCL/TK and other cross-platform runtimes.

4) Migrate application development framework to cloud

a) Apporaches: Adopt cloud based application development, testing and deployment.

b) Examples: Google App Engine, Microsoft Azure and etc.

5) Migrate repository to cloud

a) Apporaches: Adopt loud based database, storage and related services with different deployment type, service type, and support workload.

b) Examples: Amazon Map Reduce/Simple Storage Service, Google, Microsoft storage.

C. Migrate Software Access to SaaS

SaaS provides applications running on a cloud infrastructure. They are accessible from web browser or a program interface. The consumer does not manage or control the underlying cloud infrastructure. Usually SaaS can be easily integrated with other mashup applications.

1) Migrate software to syntax service composition

a) Apporaches: Adopt syntax service comoposition to use vary services from different vendors. There arey two typical approaches: service choreograph and service orchestration.

b) Examples: Google Maps, Salesforce.com and Zoho productivity and collaboration suite.

2) Migrate software to semantic service composition

a) Apporaches: Adopt semantic service composition automatically using service semantic information and ontologies.

b) Examples: Many WordNet based sematic servcie compositon approaches but few in commercial use [30].

V. FUTURE CHALLENGE AND DIRECTION

In response to the gigantic cloud migration demands, many migration service vendors have emerged, offering services based on a diverse set of migration techniques. Typical vendors include Racemi, CohesiveFT, AppZero, CliQr and Ravello. IBM, Amazon, Rackspace, HP and other cloud service vendors also provide their own cloud migration tools or assist tools. Thus, due to the diversity and complexity of the application to be migrated as well as various constraints and limitations of cloud service, it is extremely difficult for single vendor to migrate an application entirely on its own. And, cloud migrating is considered costly, labor-intensive, and error-prone due to the complexity of the applications and cloud computing environment. How to perform cloud migration in an automatic and intelligent way is the direction of future. With more and more cloud services available with the high availability, QoS guarantee and security level the SaaS will take over the IaaS and PaaS for its simplicity and efficiency.

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