Cloud communications: survey on architecture of Internet- based networks for cloud services

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The cloud communications are Fiber Channel Technology or Internet-accessed voice, data and video communications where storage, switching and telecommunications applications are hosted by a third-party outside of the end-user devices. The applications are accessed via the Web or other type of interface instead of user's local storage, independently of time and place as well as the type of user equipment. In cloud computing, the services are delivered and used over the Internet or other technology and are paid for by cloud customer on an "as-needed, pay-per-use" business model. The cloud infrastructure is maintained by the cloud provider, not by the individual cloud customer. The cloud computing networks are large groups of server farms and data centers with specialized connections to distribute data storage and processing. The cloud service providers take advantage of low-cost computing technology. This shared IT infrastructure contains large pools of systems that are linked together. The virtualization techniques are used to maximize the power of cloud computing. It isolates software from hardware and so provides a mechanism to quickly reallocate applications across servers based on computational demands. Virtualization also isolates the end-user from the cloud infrastructure allowing the access to the services regardless of time and place. The cloud computing has been widely recognized as the next generation computing infrastructure. It offers certain advantages by allowing users elastically to utilize resources at low cost in an on-demand fashion for provided infrastructure (e.g., servers, networks, and storages), platforms (e.g., middleware services and operating systems), and software (e.g., application programs). The cloud computing is powerful network architecture to offer large-scale and complex applications.

Облачни комуникации, обзор на архитектурата на Интернет-базираните мрежи за облачни услуги (Сеферин Т. Мирчев, Игнат С. Станев, Росица И. Голева, Георги П. Георгиев). *Облачните комуникации са комуникации на говор, данни и видео където съхранението, комутацията и телекомуникационните приложения се предоставят от трета страна извън крайните устройства на абоната. Приложенията са достъпни през интернет мрежата или друг интерфейс вместо от локално записващо устройството на абоната, независимо от времето и мястото както и от типа оборудване на потребителя. При облачните изчисленията услугите се предоставят и използват през интернет и се заплащат от абонатите на облачни услуги чрез типичния бизнес модел "каквото е необходимо, плащане при използване". Инфраструктурата на облака се поддържа от доставчика на облачни услуги, а не от абонатите. В мрежите за облачни изчисления са големи групи от сървъри със специализирани връзки до разпределени центрове за съхранение и обработка на информация. Доставчиците на облачни услуги се възползват от ниската цена на компютърните технологии. Тази споделена ИТ инфраструктура съдържа голям брой системи, които са свързани помежду си. Техниките за виртуализация се използват, за да се максимизира производителността на облачните изчисления. Те изолират софтуера от хардуера, абоната от инфраструктурата на облака, позволявайки достъп до услугите независимо от времето и мястото, и така осигуряват механизъм за бързо преразпределяне на приложенията между сървъри според изискванията. Обработката в облака е широко призната като изчислителна инфраструктура от следващо поколение. Облачните изчисления предлагат някои предимства, като позволяват на потребителите да използват еластично на ниска цена при поискване, предоставени от доставчиците на облачни услуги, инфраструктура (например, сървъри, мрежи и памет), платформи (например, мидълуер услуги и операционни системи) и софтуер (например, приложни програми). Облачните изчисления са мощна мрежова архитектура за предоставяне на мащабни и сложни приложения.*

"Network Computing ≡ Internet Computing ≡ Cloud Computing: The next step in the evolution of IT" [1]

Introduction

Cloud computing technology is a core foundational driver of growth and innovation across the global IT landscape. Cloud computing is a technology that is used to support online IT infrastructure. It has become the new trend in delivering business applications and services. The cloud is a cost-effective, flexible and reliable IT infrastructure.

Cloud services are a broad term, referring primarily to data-center-hosted services that are run and accessed over an Internet or other infrastructure [1].

Cloud computing is a type of computing that relies on sharing computing resources rather than having local servers or personal devices to handle applications. Cloud computing is comparable to grid computing, a type of computing where unused processing cycles of all computers in a network are harnessed to solve problems too intensive for any stand-alone machine.

In cloud computing, the word “cloud” (also phrased as "The cloud") is used as a metaphor for "the Internet," so the phrase cloud computing means "a type of Internet-based or other type like Fiber Channel Technology computing," where different services - such as servers, storage and applications are delivered to an organization's computers and devices through the Internet or other global communication technologies [2].

Cloud computing is an on-demand service that has obtained mass appeal in corporate data centers. The cloud enables the data center to operate like the Internet and computing resources to be accessed and shared as virtual resources in a secure and scalable manner. Like most technologies, trends start in the enterprise and shift to adoption by small business owners.

A “vertical cloud”, or “vertical cloud computing”, is a phrase used to describe the optimization of cloud computing and cloud services for a particular vertical (e.g., a specific industry) or specific application use. The cloud provider will offer specialized functions and options that best meet industry-use and specifications. Today, the health care cloud and network management clouds are considered to be well-established vertical clouds.

Since a cloud is an online IT infrastructure, the network is also a key component. Networking theories and practice have been widely used in cloud computing [3].

In this survey, we will explain the different types of Cloud Computing services, show architectural design of cloud computing and its applications, present cloud computing key concepts and implementation and illustrate how they work, as well as discus cloud trends and challenges. The aim of this survey is to provide a better understanding of the design challenges of cloud computing and to identify important cloud trends and activities in this increasingly important area.

Cloud computing definition

Cloud computing is the delivery of computing services over the Internet or other networking technology. There are public and private clouds as well as different technological solutions on the market. Cloud services allow individuals and businesses to use software and hardware that are managed by third parties at remote locations. Examples of cloud services include online file storage, social networking sites, webmail, and online business applications. The cloud computing model allows access to information and computer resources from anywhere and anytime through available network connection. Cloud computing provides a shared pool of resources, including data storage space, networks, computer processing power, specialized corporate and user applications [4].

The generally accepted definition of Cloud Computing comes from the National Institute of Standards and Technology (NIST) [5]. The NIST definition essentially says that “Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.”

In plain terms, it is the ability for the end-users to utilize parts of bulk resources. These resources can be acquired quickly and easily.

NIST also offers up several characteristics that it sees as essential for a service to be considered “Cloud-based”. These characteristics include:

• *On-demand self-service.* The ability for an end user to sign up and receive services without the long delays that have characterized traditional IT.

• *Broad network access.* Ability to access the service via standard platforms (desktop, laptop, mobile etc).

• *Resource pooling.* Resources are pooled across multiple customers.

• *Rapid elasticity.* Capability can be scaled to cope with demand peaks.

• *Measured Service.* Billing is metered and delivered as an utility service.

Clouds, Grids, and Distributed Systems

Many discerning readers will immediately notice that the definition of Cloud Computing overlaps with many existing technologies, such as Grid Computing, Utility Computing, Services Computing, and distributed computing in general. The Cloud Computing is not only overlaps with Grid Computing, it is indeed evolved out of Grid Computing and relies on Grid Computing as its backbone and infrastructure support. The evolution has been a result of a shift in focus from an infrastructure that delivers storage and compute resources (such is the case in Grids) to one that is economy-based aiming to deliver more abstract resources and services (such is the case of Clouds). As for Utility Computing, it is not a new paradigm of computing infrastructure. It is rather a business model in which computing resources, such as computation and storage, are packaged as metered services similar to a physical public utility, like electricity or public switched telephone network or smart grid etc.. The Utility Computing is typically implemented using other computing infrastructure (e.g. Grids) with additional accounting and monitoring services.

A Cloud infrastructure can be utilized internally by a company or exposed to the public as utility computing [6]. An overview of the relationship between Clouds and other domains is presented in Figure 1.

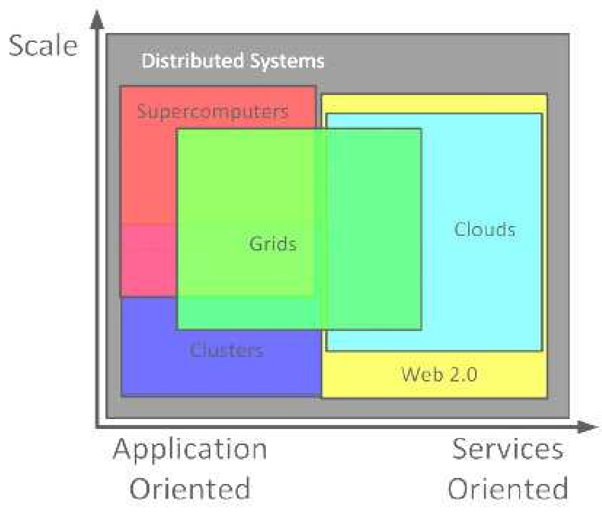

Fig. 1. Grids and Clouds Overview, source [6].

The Cloud overlaps with existing technologies like Web 2.0 that covers almost the whole spectrum of service-oriented applications. Cloud Computing lies at the large-scale side like Supercomputing and Cluster Computing that have been more focused on traditional non-service applications. Grid Computing overlaps with all these fields where it is generally considered of lesser scale than supercomputers and Clouds.

How cloud computing works

The goal of cloud computing is to apply traditional supercomputing or high-performance computing power, normally used by military and research facilities, to perform tens of trillions of computations per second in consumer-oriented applications such as financial portfolios. It delivers personalized information, provides data storage or powers large, immersive online computer games.

The cloud computing uses networks of server farms that are large groups of servers typically running low-cost consumer PC technology with specialized connections for distributed data-processing. Storage capacity and server farms form recent data centers. This shared IT infrastructure contains large pools of systems that are linked together. The virtualization techniques are used to maximize the power of cloud computing and to isolate managed services from the end-user's equipment.

Just like introducing the Client/Server model impacted almost everything we did in IT (operation IT, developing applications, etc.), Cloud computing has strong impact on the IT industry by [1]:

– New consumption and delivery model
– Optimization for massive scalability, delivery of services, etc.
– Centralized model, hybrid service acquisition models
– Support of huge numbers of mobile devices and sensors
– Internet technology-based architecture

The Cloud Computing Stack

Cloud Computing is often described as a stack, in a response to the broad range of services built on top of one another under the moniker "Cloud" [7].

The Cloud Computing stack is depicted in the diagram below (Fig. 2). Three distinct service models are shown within the cloud computing: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS).

These three categories of Cloud Computing are simplifying the way of differentiating parts of the distributed framework as:

• SaaS applications that are designed for end-users and delivered over the web.

• PaaS that is the set of tools and services designed to make coding and deploying those applications quickly and efficiently.

• IaaS that is the hardware and software that powers it all like servers, storage, networks, and operating systems.

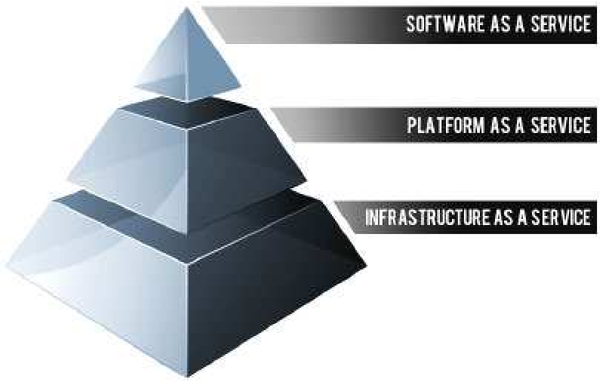

Fig. 2. Cloud Computing stack, Source [7].

The cloud architecture can be divided into 4 general layers that map to the available business models: the hardware/ data center layer; the infrastructure layer; the platform layer and the application layer (Fig.3). Each layer can be divided into sub layers for research and developing purposes.

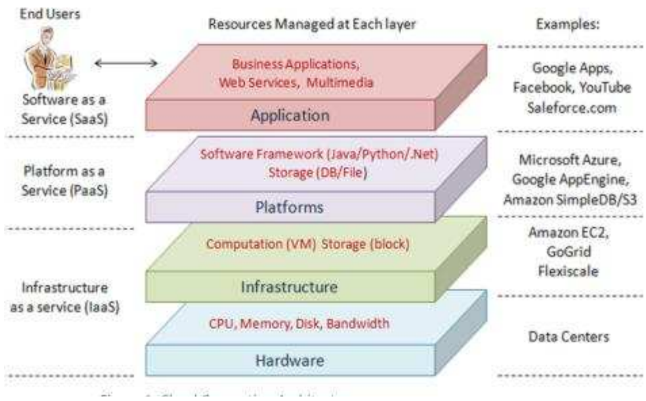

Fig. 3. Cloud computing service models, Source [8].

Software as a Service (SaaS) model provides a pre-made application, along with any required software, operating system, hardware, and network. Platform as a Service (PaaS) provides an operating system, hardware, and network. The customer installs or develops its own software and applications. The Infrastructure as a Service (IaaS) model provides just the hardware and network where the customer installs or develops its own operating systems, software and applications.

Cloud services are typically made available via a private cloud, community cloud, public cloud or hybrid cloud [9]. There is no clear distinction between different types of clouds.

Private cloud is a cloud infrastructure provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organization, a third party, or some combination of them, and it may be installed anywhere, i.e. on or off premises.

Community cloud is a cloud infrastructure that provides exclusive use of specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it might be installed and supported from any place.

Public cloud is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or governmental organizations.

Hybrid cloud is a cloud infrastructure that is a composition of two or more distinct cloud infrastructures (private, community, or public). They remain unique entities but are bounded together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

Cloud services are the most rapidly growing segment of the IT marketplace. As Figure 4 shows, International Data Corporation's (IDC) forecast for U.S. public cloud services spending will double from $37.1 billion in 2014 to more than $75 billion in 2018. SaaS will dominate public cloud services spending because most customer demand is at the application level.

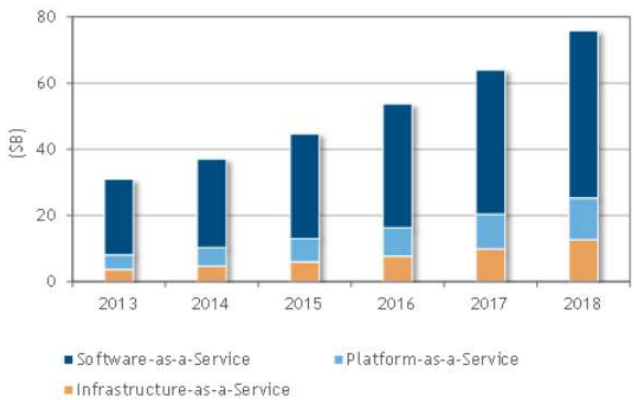

Fig. 4. U.S. Public IT Cloud Services Revenue by Segment, 2014-2018 ($), Source: IDC [10]

Cloud architecture

Cloud computing is considered as a powerful network architecture to perform large-scale and complex computing. Clouds are developed to address

Internet-scale or global scale computing problems. Clouds are usually referred to as a large pool of computing and/or storage resources, which can be accessed via standard protocols and interfaces. Some of these interfaces are mentioned in many sources as 'abstract' due to the virtualization process. Clouds can be built on top of many existing protocols such as Web Services (Web Services Description Language - WSDL, Simple Object Access Protocol -SOAP), and some advanced Web 2.0 technologies such as Representational State Transfer (REST), Rich Site Summary (RSS), Asynchronous Javascript and XML (AJAX), etc. [6]. It is possible for Clouds to be implemented over existing Grid technologies leveraging more than a decade of community efforts in standardization, security, resource management, and virtualization support [29].

There are multiple versions of definition for Cloud architecture. Often it is used a four-layer architecture for Cloud Computing in comparison to the Grid architecture, composed of 1) fabric, 2) unified resource, 3) platform, and 4) application Layers (Fig.5).

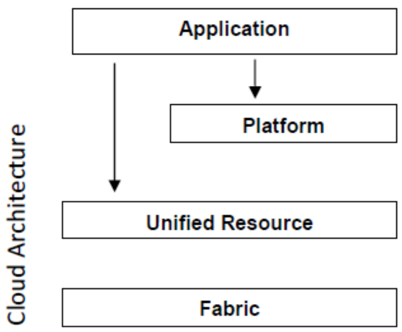

Fig. 5. Cloud Architecture, Source [6].

The *fabric layer* contains the raw hardware level resources, such as computer resources, storage resources, and network resources. The *unified resource layer* contains resources that have been abstracted/encapsulated (usually by virtualization) so they can be exposed to upper layers and end users as integrated resources, for instance, a virtual computer/cluster, a logical file system, a database system, etc. The *platform layer* adds on a collection of specialized tools, middleware and services on top of the unified resources to provide a development and/or deployment platform. For instance, it is a Web hosting environment, a scheduling service, etc. Finally, the *application layer* contains the applications that would run in the Clouds.

Virtualization improves resource utilization and energy efficiency – helping to substantially reduce server maintenance overhead and providing fast disaster recovery and high availability. Virtualization has been very important for cloud computing, because it isolates software from hardware and so provides a mechanism to quickly reallocate applications across servers based on computational demands.

Virtualization was a major step towards cloud infrastructure; however, the service component was still missing. Virtualized environments managed by internal system administrators and by default virtualization platforms do not provide the abstraction layer that enables cloud services. Layer of abstraction and on-demand provisioning must be provided on top of the cloud to enable cloud services (Fig. 6). This service layer is an important attribute of any cloud environment. It hides the complexity of the infrastructure and provides a cloud-management interface to users. Depending on the interface implementation, a cloud-management interface can be accessed through a management dashboard, REST or SOAP web services, programming APIs, or other services [11].

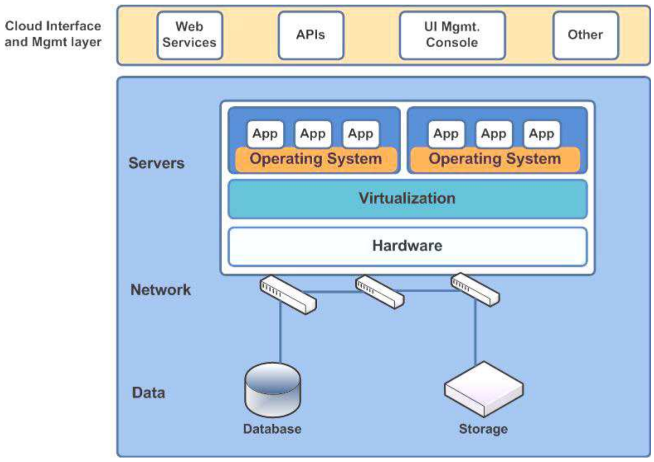

Fig. 6. Simplified cloud infrastructure, Source [11].

Cloud management interfaces provide functions allowing users to manage a cloud lifecycle. For instance, users can add new components to the cloud such as servers, storage, databases, caches, and so on. Users can use the same interface to monitor the health of the cloud and perform many other operations.

ITU cloud computing infrastructure

The cloud infrastructure which includes processing, storage, networking and other hardware resources as well as software assets is presented in [12]. Abstraction and control of physical resources are essential means to achieve the on-demand and elastic characteristics of cloud infrastructure. In this way, physical resources can be abstracted into virtual machines (VMs), virtual storages and virtual networks. The abstracted resources are controlled to meet cloud service customers' needs.

The main characteristics of cloud infrastructure are: network centric; on-demand resource provisioning; elasticity; high availability; resources abstraction [30].

Typically, there are several types of networks involved in cloud computing services delivery and composition, such as the intra-datacenter network and inter-datacenter network, as well as the access and core transport network, etc. To illustrate the cloud computing network concepts, a generic network model supporting cloud computing infrastructure, is shown in Figure 7. The generic network model consists of the following blocks:

1) Intra-datacenter network connecting local cloud infrastructures, such as the datacenter local area network connecting servers, storage arrays and devices (e.g., firewalls, load balancers, application acceleration devices).

2) Access and core transport network connecting cloud service customers to access and consume cloud services.

3) Inter-datacenter network connecting remote cloud infrastructures. These infrastructures may be owned by the same or different cloud service providers.

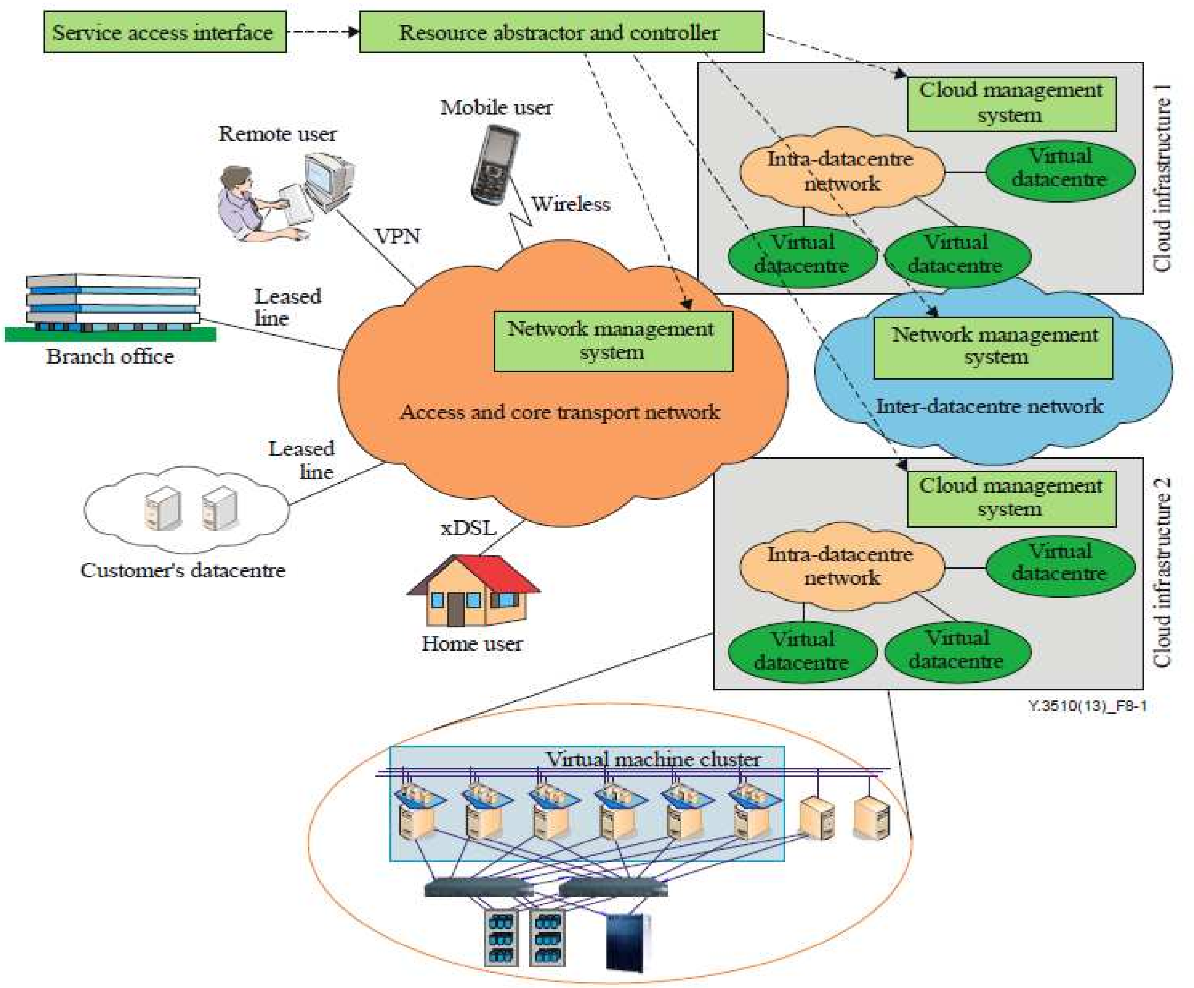

Fig. 7. Generic network model for cloud infrastructure, Source [12].

NIST cloud computing architecture

The NIST Reference Architecture describes five major actors with their roles and responsibilities using the developing Cloud Computing Taxonomy. The NIST cloud computing reference architecture defines five major actors: *Cloud Consumer, Cloud Provider, Cloud Broker, Cloud Auditor* and *Cloud Carrier* (Fig. 8). These core individuals have key roles in the realm of cloud computing. Each actor is an entity (a person or an organization) that participates in a transaction or process and/or performs tasks in cloud computing.

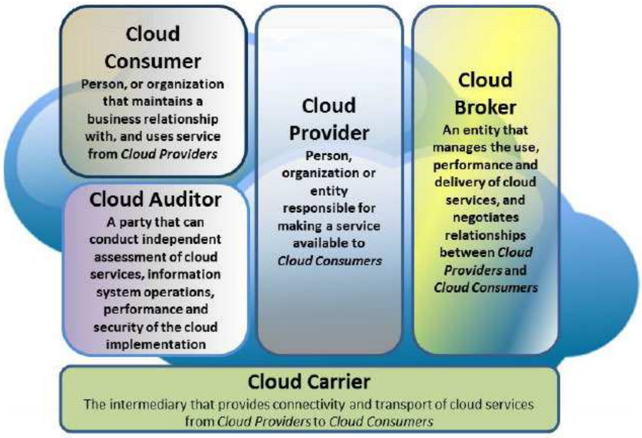

Fig. 8. Cloud Actors, source [9].

The Cloud Consumer is an individual or organization that acquires and uses cloud products and services. The purveyor of products and services is the Cloud Provider. Because of the possible service offerings (Software, Platform or Infrastructure) allowed for by the cloud provider, there will be a shift in the level of responsibilities for some aspects of the scope of control, security and configuration.

The Cloud Broker acts as the intermediary between the consumer and the provider and will help consumers through the complexity of cloud service offerings and may also create value-added cloud services. The Cloud Auditor provides a valuable inherent function for the government by conducting the independent performance and security monitoring of cloud services. The Cloud Carrier is the organization which has the responsibility of transferring the data, somewhat akin to the power distributor or other utility provider. An overview of the NIST cloud computing reference architecture, which identifies the major actors, their activities and functions in cloud computing is presented in Figure 9 [13]. The diagram depicts a generic high-level architecture and is intended to facilitate the understanding of the requirements, uses, characteristics and standards of cloud computing.

Service Orchestration refers to the composition of system components to support the Cloud Provider' activities in arrangement, coordination and management of computing resources while providing cloud services to Cloud Consumers.

As a major architectural component of the cloud, security and privacy concerns need to be addressed. These needs set the level of confidence and trust and create an atmosphere of acceptance and the cloud's ability to provide a trustworthy and reliable system.

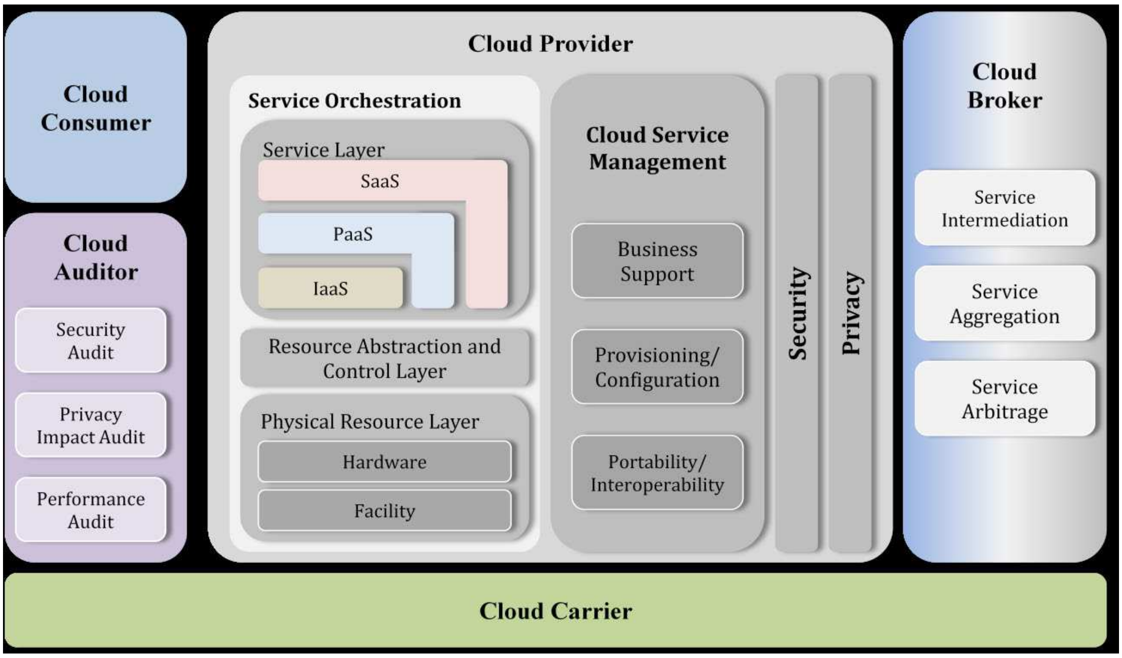

Fig. 9. NIST Conceptual Reference Model, Source [13].

IBM cloud computing architecture

The IBM Cloud Computing Reference Architecture (CCRA) is structured in a modular fashion (similar to the Service Oriented Architecture Reference Model) (Fig.10) [1,31]. On its highest level of abstraction, it defines a basic set of architectural elements, which are refined to the next level of detail. This modular approach allows refinement of the CCRA architectural elements independently from each other by the respective small and medium enterprises. IBM's CCRA addresses the three major roles in any cloud computing environment: Cloud service provider, Cloud service developer and Cloud service consumer.

Figure 11 represents a complete cloud computing reference architecture infrastructure. As you can see from the lower parts of the box, building of the cloud starts with hardware infrastructure (servers, storage, network devices, and facilities). Next, adding cloud software (i.e. OpenStack) helps creation and delivery of some of the basic cloud functionality such as IaaS, and the operational and business support services for the cloud. Then adding a PaaS solution, for example IBM Bluemix is a final deployment step in system development.

You can add in or deliver SaaS applications and combine them together to create business processes as a service. Security, performance, scaling, resiliency, and governance are also critical elements of a cloud solution. The left side of the figure shows a view of the consumers of cloud (end users). The right side shows a view of the producers of cloud content, applications and services.

CCRA 4.0 categorizes the cloud business models and corresponding architecture by the following "cloud adoption patterns" (Fig. 12): *Cloud Enabled Data Center (IaaS); Platform-as-a-Service (PaaS) adoption pattern; Software-as-a-Service (SaaS); Cloud Service Providers; Mobile; Analytics.* For each cloud adoption patterns, CCRA identifies: Common architecture patterns that describe the business drivers, the use-cases and the technologies that underlie each type of cloud computing implementation; Common architecture patterns for items that cut across all the adoption patterns including security, resiliency, performance, etc.

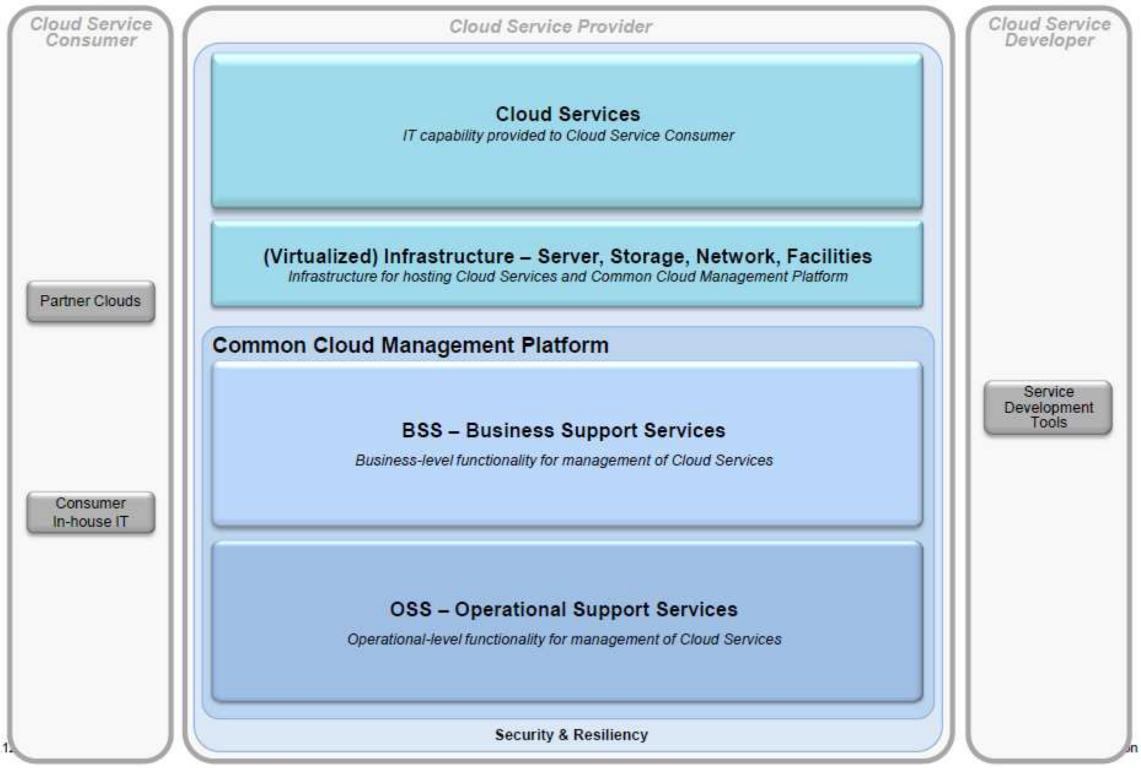

Fig. 10. Cloud Computing Reference Architecture, Source [1].

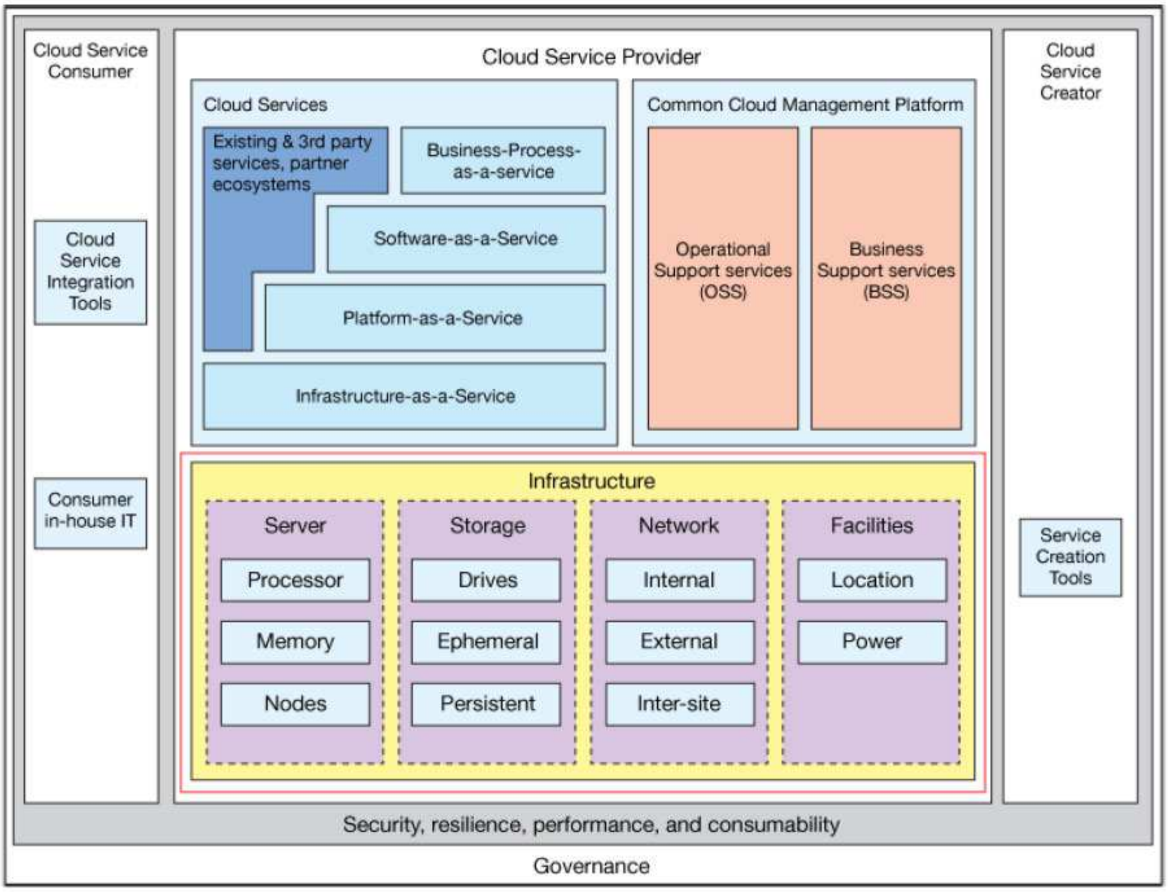

Fig. 11. IBM cloud computing reference architecture infrastructure, Source [14].

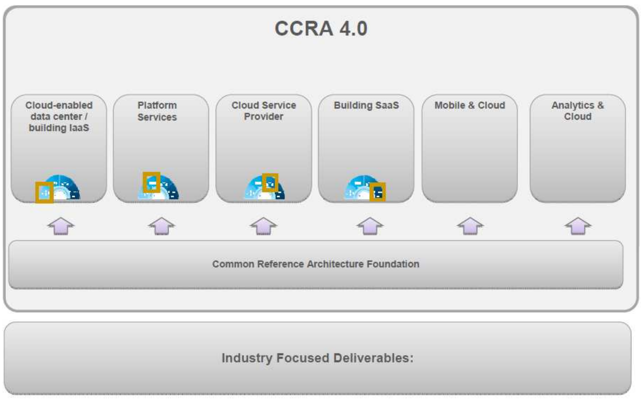

Fig. 12. Main workstreams of cloud computing reference architecture 4.0, Source [15].

The standards for connecting the computer systems and the software needed to make cloud computing work are not fully defined at present time, leaving many companies to define their own cloud computing technologies. Cloud computing systems offered by companies, like IBM's "Blue Cloud" technologies for example, are based on open standards and open source software which link together computers that are used to deliver Web 2.0 capabilities like mash-ups or mobile commerce.

Cisco digital network architecture

The enterprise network architectures are being challenged by the evolution of digital businesses that are embracing mobile, cloud, video, and Internet– of–Things (IoT) technologies. Often referred to as the digitization of businesses, the adoption of these technologies can impact our lives much as the introduction of the Internet and World Wide Web did 20 years ago. The advent of big data and analytics helps to enable better real–time decision making, automation, and efficiencies necessary to deliver such digitalized applications competitively. Additionally, the wide availability of cloud services is supporting these trends. The cloud is rapidly equalizing the opportunities for small and medium companies to cost–effective and access of advanced IT services. It was possible previously only within reach of established organizations [16].

The evolution toward a dynamic, ubiquitous digitalized business does not come without risks. Universal connectivity opens up new, and often, devastating security risks. Complexity of network operations is expected to increase. Such operations become more dynamic, generating more events and data for an increasing number of users and applications. The network is becoming difficult for management and operation.

Cisco Digital Network Architecture (DNA) offers a new blueprint for the digital organization. The network is extended to embrace data center, cloud and IoT infrastructures while maintaining the traditional high availability, scalability and performance characteristics. The DNA infrastructure is designed to deliver services like: network services for enabling the ubiquitous connectivity; security services for protecting the data and user integrity; and digital services for optimizing the business applications. As a result, Cisco DNA provides the platform for digital solution delivery to enable a superior workforce and customer experience while simplifying business operations. Figure 13 shows an overview of the Cisco Digital Network Architecture.

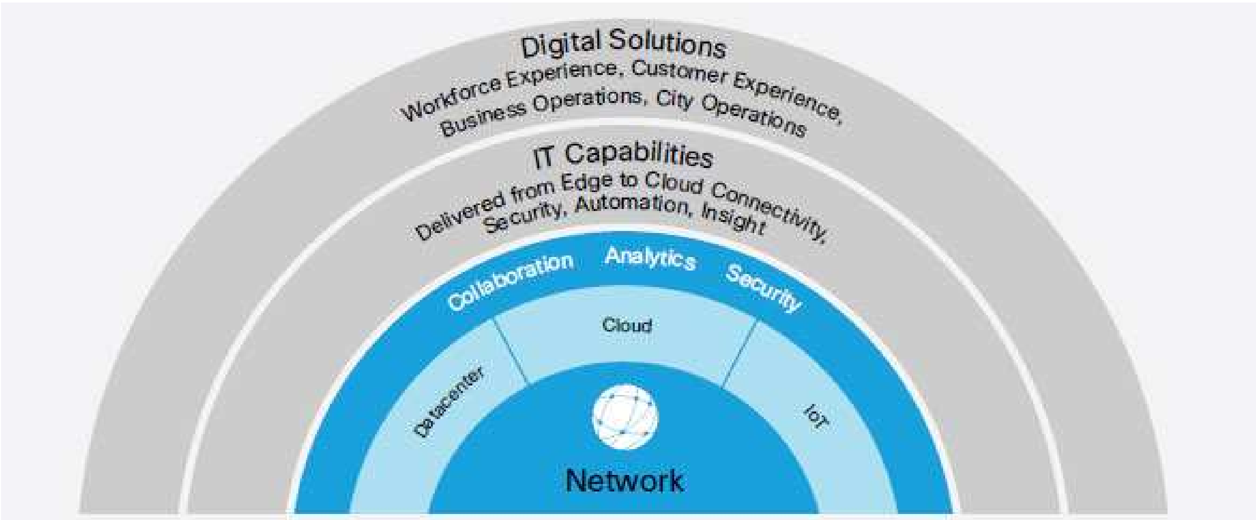

Fig. 13. Cisco Digital Network Architecture Vision, Source [16].

The Cisco DNA is built to facilitate fast and flexible network services that support digitalized business processes. The DNA centers are around a network infrastructure that is not only fully programmable and open to third–party innovation, but can also fully and seamlessly integrate the cloud as an infrastructure component. The DNA controller facilitates simple, automated, and programmatic deployment of network services. It brings the notion of user and application–aware policies into the foreground of network operations. With DNA, the network can provide continuous feedback to simplify and optimize network operations and to support digitalized applications to become inherently network–aware.

Mobile cloud computing architecture

Mobile cloud computing (MCC) has been introduced to be a potential technology for mobile services together with an explosive growth of the mobile applications and emerging of cloud computing concept. MCC integrates the cloud computing into the mobile environment and overcomes obstacles related to the performance (e.g., battery life, storage, and bandwidth), environment (e.g., heterogeneity, scalability, and availability), and security (e.g., reliability and privacy). MCC brings new types of services and facilities to mobile users allowing them to take full advantages of cloud computing.

The general architecture of MCC is shown in Fig. 14. The mobile devices are connected to the mobile networks via base stations (e.g., base transceiver station, access point, or satellite) that establish and control the connections (wireless links) and functional interfaces between the network and mobile devices.

Mobile users' requests and information (e.g., ID and location) are transmitted to the central processors that are connected to servers providing mobile network services. Mobile network operators can provide services to mobile users as authentication, authorization, and accounting based on the home agent and subscribers' data stored in databases. After that, the subscribers' requests are delivered to a cloud through the Internet. In the cloud, cloud controllers process the requests to provide mobile users with the corresponding cloud services. These services are developed with the concepts of utility computing, virtualization, and service-oriented architecture (e.g., web, application, and database servers). .

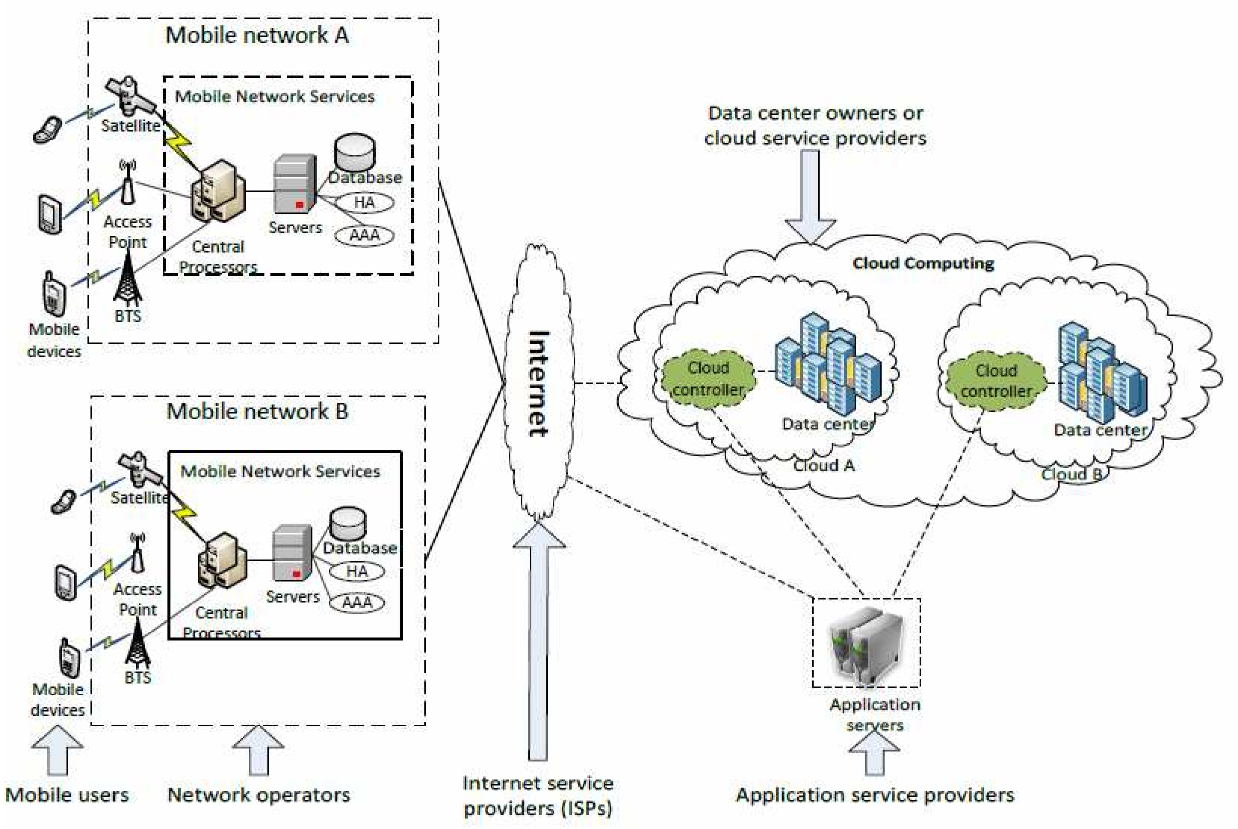

Fig. 14. Mobile cloud computing architecture, Source [17].

Cloud computing is a large-scale distributed network system implemented based on a number of servers in data centers. Data centers provide the hardware facility and infrastructure for clouds. In data center layer, a number of servers are linked with high-speed networks to provide services for customers. Typically, data centers are built in less populated places, with high power supply stability and a low risk of disaster.

Cloud computing is known to be a promising solution for mobile computing because of many reasons (e.g., mobility, communication, and portability

Cloud computing architecture in Bulgaria

Cloudware architecture

The platform of the Cloudware architecture is designed in a way that even in the unlikely event when all of its control servers go offline, the active Cloud servers on the hypervisors will continue to process uninterrupted (Fig. 15) [18].

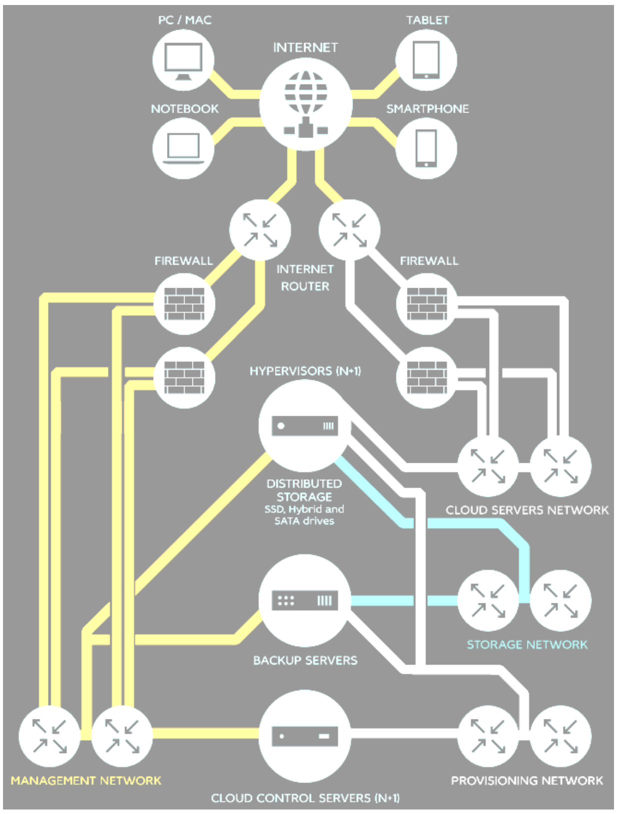

Fig. 15. Cloudware architecture, Source [18].

The redundancy is organized in an N+1 configuration, wherein the content and configuration of the main server is replicated in real-time on at least one other server, which can automatically replace the first one in case of failure. A broad range of the server parameters are monitored 24x7x365 in real-time through a special IPMI controller and a specialized monitoring system – temperature of the processors of the whole system and hard drives, performance of the cooling fans, voltage values of the power modules, S.M.A.R.T status of the hard disk drives, used disk space, RAM load, processor load, network connections, number of running processes, etc. The monitoring allows on-time diagnosis, prevention or troubleshooting of possible problems on the server. The network connectivity of the servers is completely redundant and all connections go through several independent network controllers and devices.

VMware Cloud Foundation™ platform

With the Software-Defined Data Center (SDDC), VMware laids out the vision for the architecture of the hybrid cloud [19]. SDDC redefines the architecture and operational model of the data center, enabling IT to complete the transition to hybrid cloud and maximize its benefits (Fig. 16). In an SDDC, compute, storage, and networking services are decoupled from underlying hardware infrastructure and abstracted into logical pools of resources that can be more flexibly provisioned and managed.

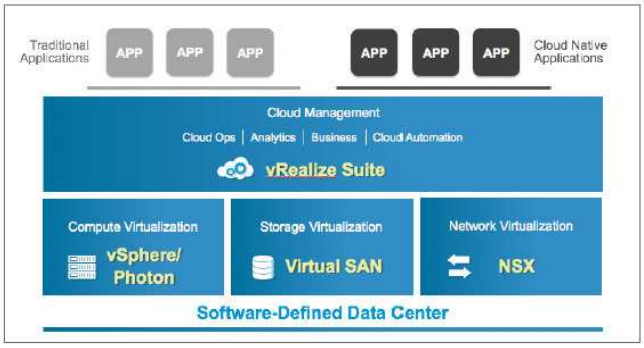

Fig. 16 Software-Defined Data Center Architecture, Source [19].

To accelerate the customer journey to SDDC, VMware has introduced VMware Cloud Foundation™ that is a new unified SDDC platform for the private and public cloud [20]. Cloud Foundation brings together VMware's compute, storage, and network virtualization into a natively integrated stack that can be deployed on premises or run as a service from the public cloud (Fig. 17).

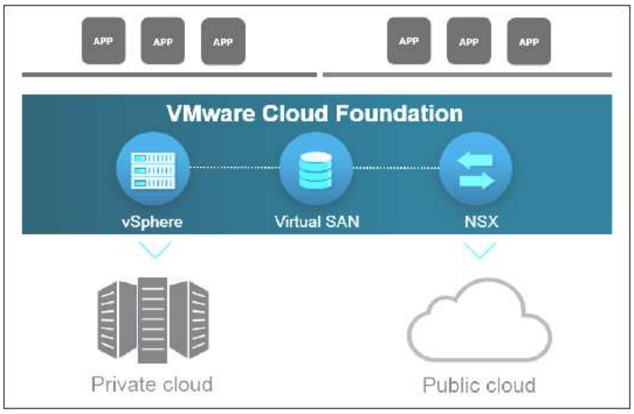

Fig. 17. VMware Cloud Foundation Software Stack, Source [20]

The core components of VMware Cloud Foundation are VMware vSphere (cloud computing virtualization platform), Virtual Storage Area Network (SAN) and Networking and Security software product family (NSX). VMware Cloud Foundation also comes with VMware SDDC Manager that automates the entire system lifecycle and simplifies software operations. In addition, it can be further integrated with VMware vRealize® Suite, Horizon® and VMware Integrated OpenStack.

VMware Cloud Foundation integrates computing, storage, and networking into a single layer of software, ensuring full interoperability of the entire software stack to deliver the easiest path to deploy a virtualized infrastructure. It takes hyper-convergence to the next level by extending the convergence of computing and storage by including network virtualization. This allows simpler network management and elastic scalability at data-center scale. VMware Cloud Foundation can be run as a service from leading cloud service providers, establishing a common operational model between private and public clouds, which leverages existing administration skill-sets, tools, and processes.

Cloud services

Cloud services are made available to users on demand via the Internet or other technology from a cloud computing provider's servers. It could be provided by a company's own on-premises servers or any other server farm. Cloud services are designed to provide easy, scalable access to applications, resources and services, and are fully managed by a cloud service provider [32].

A cloud service can dynamically scale to meet the needs of its users, and because the service provider supplies the hardware and software necessary for the service, there's no need for a company to provide or deploy its own resources or allocate IT staff to manage the service. Examples of cloud services include online data storage and backup solutions, Web-based e-mail services, hosted office suites and document collaboration services, database processing, managed technical support services and more.

Cloud consumers need service-level agreements (SLA) to specify the technical performance requirements fulfilled by a cloud provider. Depending on the requested services, the activities and usage scenarios can be different among cloud consumers. Some example cloud services available to a cloud consumer are presented in Figure 18.

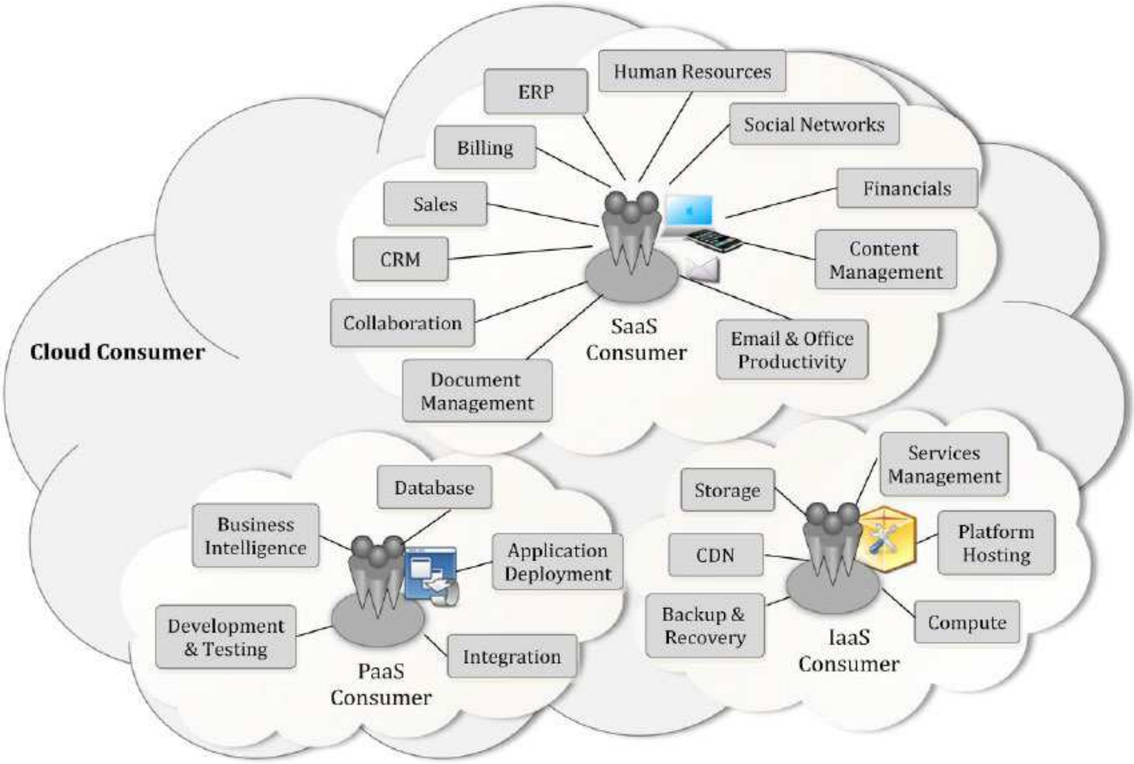

Fig. 18. Example services available to a cloud consumer, Source [13].

Software as a Service (SaaS) applications are in the cloud and are accessible via a network. The consumers of SaaS can be organizations that provide their members an access to software applications, end users who directly use software applications, or software application administrators who configure applications for end users. SaaS consumers can be billed basing on the number of end users, the time of use, the network bandwidth consumed, and the amount of data stored or the duration of stored data.

Cloud consumers of Platform as a Service (PaaS) can employ the tools and execution resources provided by cloud providers to develop, test, deploy and manage the applications hosted in a cloud environment. PaaS consumers can be application developers who design and implement application software, application testers, who run and test applications in cloud-based environments, application implementers, who publish applications into the cloud, and application administrators who configure and monitor application performance on a platform. PaaS consumers can be billed according to, processing, database storage, network resources consumed by the application, and the duration of the platform usage.

Consumers of Infrastructure as a Service (IaaS) have access to virtual computers, network-accessible storage, network infrastructure components, and other fundamental computing resources on which they can deploy and run arbitrary software. The consumers of IaaS can be system developers, system administrators and IT managers who are interested in creating, installing, managing and monitoring services for IT infrastructure operations. IaaS consumers are provisioned with the capabilities to access these computing resources, and are billed according to the amount or duration of resources usage, such as CPU hours used by virtual computers, volume and duration of data stored, network bandwidth consumed, number of IP addresses used for certain time slots.

Cloud in data center and for small business

Voice has been the primary business communications tool forever. But workforce communications are rapidly evolving to include a broad mix of voice, email, instant message, presence, conferencing, video, and IP messaging all fully accessible from mobile phones and tablets as well as desk phones and desktop computers. The nature of work is also undergoing a radical transformation as workforces become increasingly distributed, mobile, and not tied to a physical location. The tools they use are becoming virtualized and accessible via websites and mobile apps. Mobile enterprise device usage is outpacing overall market growth [10]. Companies are embracing cloud delivery capabilities including software-as-a-service (SaaS), virtual desktop infrastructure, cloud storage, security-as-a-service, and mobile edge computing. Mainstream acceptance of cloud delivery for IT solutions paves the way for cloud-based communications solutions.

Cloud computing has gained tremendous popularity in recent years. By outsourcing computation and storage requirements to public providers and paying for the services used, customers can relish upon the advantages of this new paradigm. Cloud computing provides a comparably lower-cost, scalable, a location-independent platform for managing clients' data. Compared to a traditional model of computing, which uses dedicated in house infrastructure, cloud computing provides unprecedented benefits regarding cost and reliability. Cloud storage is a new cost-effective paradigm that aims at providing high availability, reliability, massive scalability and data sharing for end-user information. However, outsourcing data to a cloud service provider introduces new challenges from the perspectives of data correctness and security [21].

Cloud computing has started to obtain mass appeal in corporate data centers as it enables the data center to operate like the Internet through the process of enabling computing resources access and sharing them as virtual resources in a secure and scalable manner.

For a small and medium size business (SMB), the benefits of cloud computing are currently driving adoption. In the SMB sector, there is often a lack of time and financial resources to purchase, deploy and maintain an infrastructure (e.g. the software, server and storage). In cloud computing, small businesses can access these resources and expand or shrink services as business needs change. The common pay-as-you-go subscription model is designed to let SMBs easily to add or remove services and typically pay only for resource usage.

In 2017, cloud challenges declined across the board with the exception of governance/control, which remained flat. Managing cloud spend fell only slightly. The expertise, security, and spend were all tied for the top challenge with 25% of respondents citing each as a significant challenge (Fig. 19).

International Data Corporation (IDC) predicts cloud IT infrastructure spending to grow and reach $53.1B billion by 2019 and the IT infrastructure spending to be 46% of total expenditures on enterprise IT infrastructure. Worldwide spending on public cloud services will grow and reach more than $141B in 2019. The IDC predicts the Software as a Service (SaaS) to remain the dominant cloud computing type, by capturing more than two-thirds of all public cloud spending. The worldwide spending on Infrastructure as a Service (IaaS) and Platform as a Service (PaaS) will grow at a faster rate than SaaS [22].

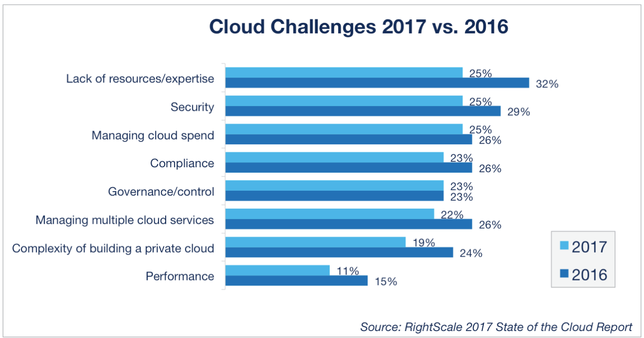

Fig. 19. Cloud Challenges Decline Overall.

New emerging trends in 2017 are shown in [23]. Hybrid cloud is the preferred enterprise strategy, but private cloud adoption fells. Cloud users are running applications in multiple clouds. The competition among public cloud providers will increase. Enterprises will optimize the cloud costs by focusing on renewed solutions. The use of solutions like a Docker for open-source initiative designed to automate the deployment of applications within virtualized software containers using an additional abstraction layer and operating system-level virtualization will be useful for most of the end-users.

Cloud computing strategy of European Union

Within the Digital Single Market Strategy for Europe, the key role of cloud computing is established through the European Cloud Initiative and through the initiative on Building an European Data Economy [24]. The latter seeks to establish a free flow of data in Europe, as well as facilitating portability of data and switching of cloud service providers.

The European Cloud Initiative focuses on:

• An European Open Science Cloud that is a trusted, open environment for storing, sharing and re-using scientific data and results.

• An European Data Infrastructure that is a world-class digital infrastructure to securely access, move, share and process data in Europe.

The current policy of the European Union on cloud computing [25] is set within the Digital Single Market Strategy for Europe where it plays a key role through the European Cloud Initiative, the European Free Flow of Data Initiative and the emerging issues related to ownership, access, and portability of data and switching of cloud service providers.

The strategy includes the following three key actions.

1. Safe and Fair Contract Terms and Conditions

The aim of the cloud computing strategy was to develop model contract terms that would regulate different issues. Cloud computing contracts essentially create a framework in which the user has access to infinitely scalable and flexible IT capabilities according to needs.

2. Cutting through the jungle of Standards

Despite numerous standardization efforts, mostly led by suppliers, clouds might be developed in a way that lacks interoperability, data portability and reversibility, all crucial for the avoidance of lock-in. The priority now is to deploy existing standards to develop confidence in cloud computing via comparable service stacks as well as interoperable and diverse offerings. In addition to identifying the concerned standards compliance certification is needed.

3. Establishing a European Cloud Partnership

The European Cloud Partnership (ECP) brings together the industry and the public sector to work on common procurement requirements for cloud computing in an open and fully transparent way. The public sector has a key role to play in shaping the cloud computing market. Part of the ECP is the Cloud-for-Europe (C4E) initiative aiming at helping Europe's public authorities to procure cloud products and services so as to build trust in European cloud computing.

The cloud computing strategy initiatives unveiled by the Commission in 2012 for unleashing the potential of cloud computing in Europe. The strategy outlined actions to deliver a net gain of 2.5 million new European jobs, and an annual boost of €160 billion to the European Union GDP (around 1%), by 2020.

Teaching cloud computing

Cloud computing is a new computing paradigm that is continuously evolving and spreading. Cloud computing builds on a wide range of different computing technologies such as high-performance computing, distributed systems, virtualization, storage, networking, security, management and automation, service-oriented architecture, business process management, service-level agreement, quality of service, etc. Some technologies that dominate significant amount of time as well as a prediction of the dominant technologies in future are presented in Fig. 20.

Many experts believe it will become the dominant IT service delivery model by the end of the decade. As a result, universities worldwide are introducing cloud computing technologies in their curricula by updating existing courses or developing new ones [26].

TeachCloud (a modeling and simulation environment for cloud computing) is an excellence cloud computing teaching tool. TeachCloud can be used to experiment with different cloud components such as: processing elements, data centers, storage, networking, service level agreement constraints, web-based applications, service oriented architecture, virtualization, management, automation, and business process management. TeachCloud is a comprehensive, easy-to-use, efficient cloud computing modeling and simulation toolkit.

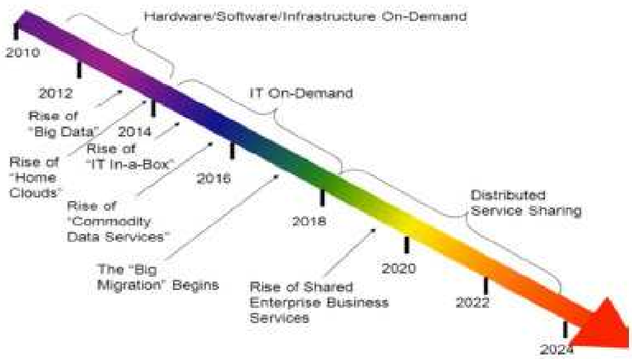

Fig. 20. Emergence of technology, Source [27]

Conclusion

With the significant advances in Information and Communications Technology over the last half century, there is an increasingly perceived vision that computing will one day be the 5th utility (after water, electricity, gas, and telephony) [28]. This computing utility, like all other four existing utilities, will provide the basic level of computing service that is considered essential to meet the everyday needs of the general community. To deliver this vision, a number of computing paradigms have been proposed, of which the latest one is known as Cloud computing.

Cloud Computing is a term that does not describe a single thing – rather it is a general term that sits over a variety of services from Infrastructure as a Service at the base, through Platform as a Service as a development tool and through to Software as a Service replacing on premise applications [7].

This paper explains different types of Cloud Computing services and illustrates how they work. It also presents cloud computing key concepts, architectural principles and implementation, as well as cloud trends and challenges in this increasingly important area.

Cloud Computing is a rapidly accelerating revolution within IT and will become the default method of IT delivery moving into the future – organizations would be advised to consider their approach towards beginning a move to the clouds sooner, rather than later because:

- Cloud Computing is a disruptive change to the way IT services are delivered, shifting to the third compute model in the evolution of IT.
- A solid Cloud Computing Architecture is required to successfully and economically manage Clouds.
- The Journey to Cloud requires an integrated and orchestrated approach.
- Customers are adopting Cloud Computing today.
- Adoption often starts in the Development and Test Environments.
- The Benefits of Cloud Computing are real.

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