UNIT-I

Computing Paradigms, Cloud Computing Fundamentals, Cloud Computing Architecture and Management

COMPUTING PARADIGMS

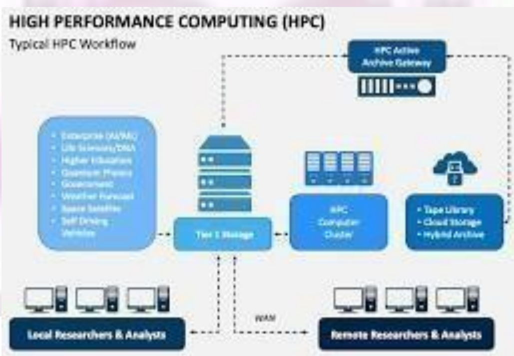
Computing Paradigms: High-Performance Computing, Parallel Computing, Distributed Computing, Cluster Computing, Grid Computing, Cloud Computing, Bio computing, Mobile Computing, Quantum Computing, Optical Computing, Nan computing.

HIGH-PERFORMANCE COMPUTING

In high-performance computing systems, a pool of processors (processor machines or central processing units [CPUs]) connected (networked) with other resources like memory, storage, and input and output devices, and the deployed software is enabled to run in the entire system of connected components.

The processor machines can be of homogeneous or heterogeneous type. Thelegacy meaning of high- performance computing (HPC) is the supercomputers; however, it is not true in present-day computing scenarios. Therefore, HPC canalso be attributedto meanthe other computing paradigms that are discussed in the forthcoming sections, as it is a common name for all these computing systems.

Thus, examples of HPCinclude a small cluster of desktop computers or personal computers (PCs) to the fastest supercomputers. HPC systems are normally found in those applications where it is required to use or solve scientific problems. Most of the time, the challenge in working with these kinds of problems is to perform suitable simulation study, and this can be accomplished by HPC without anydifficulty. Scientific examples such as protein folding in molecular biology and studies on developing models and applications based on nuclear fusion are worth noting as potential applications for HPC.



PARALLEL COMPUTING

Parallel computing is also one ofthe facets ofHPC. Here, a set ofprocessors work cooperatively to solve a computational problem. These processor machines or CPUs are mostly of homogeneous type. Therefore, this definition is *the same* as that of HPC and is broad enough to include supercomputers that have hundreds or thousands of processors interconnected with other resources. One can distinguish between *conventional* (also known as serial or sequential or Von Neumann) computers and parallelcomputers inthe waythe applications are executed.

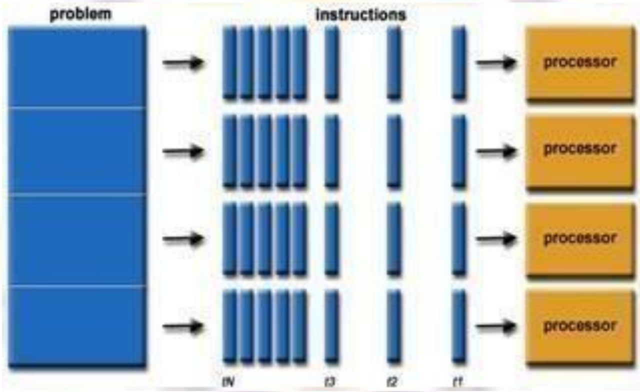


Fig2 ParallelComputing

In serial or sequential computers, the following apply:

1) It runs on a single computer/processor machine having a single CPU.
2) A problem is broken down into a discrete series of instructions.Instructions are executed one after another.

In parallel computing, since there is simultaneous use of multiple processormachines,thefollowing apply:

1) It is runusing multiple processors (multiple CPUs).
2) A problem is broken down into discrete parts that can be solved concurrently.
3) Each part is further broken down into a series of instructions.
4) Instructions from each part are executed simultaneously on different processors.
5) An overall control/ coordination mechanism is employed.

DISTRIBUTED COMPUTING

Distributed computing is also a computing system that consists of multiple computers or processor machinesconnected throughanetwork, whichcanbehomogeneousorheterogeneous, butrun as a single system. The connectivity can be such that the CPUs in a distributed system canbe physically close together and connected by a local network, or they can be geographically distantand connected by a wide area network. The heterogeneity in a distributed system supports any number of possible configurations in the processor machines.

Distributed computing systems are advantageous over centralized systems, because there is a supportfor the following characteristicfeatures:

Scalability: It is the ability of the system to be easily expanded by adding more machines as needed,and vice versa, without affecting the existing setup.

Redundancy or replication: Here, several machines can provide the same services, so that even ifone isunavailable (orfailed), workdoesnot stopbecause other similar computing supportswillbe available.

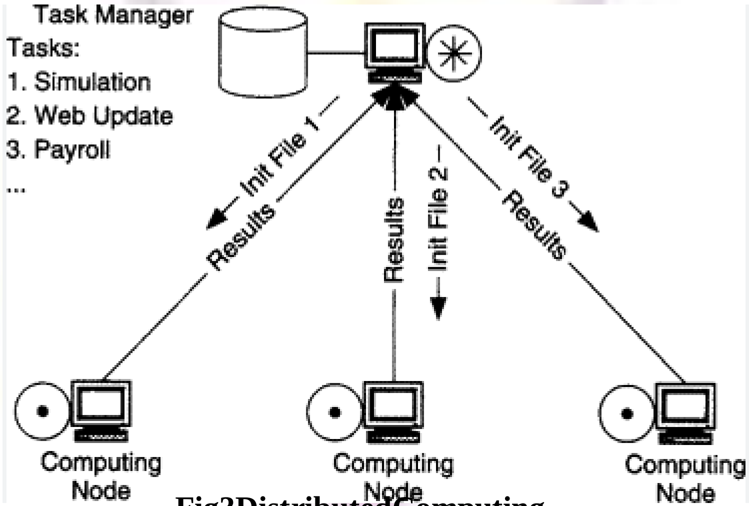


Fig3DistributedComputing

CLUSTER COMPUTING

A cluster computing system consists of a set of the same or similar type of processor machines connected using a dedicated network infrastructure. Allprocessor machines share resources such as a common home directory and have software such as a message passing interface (MPI) implementation installed to allow programs to be run across all nodes simultaneously. This is also a kind ofHPC category. The individualcomputers ina cluster canbe referred to as *nodes*. The reason to realize a cluster as HPC is due to the fact that the individual nodes can work together to solve a problem larger than any computer can easily solve. And, the nodes need to communicate with one another inorderto workcooperatively and meaningfully together to solve the problem in hand.

If we have processor machines of heterogeneous types in a cluster, this kind of clusters become a subtype and still mostlyare inthe experimentalor researchstage.

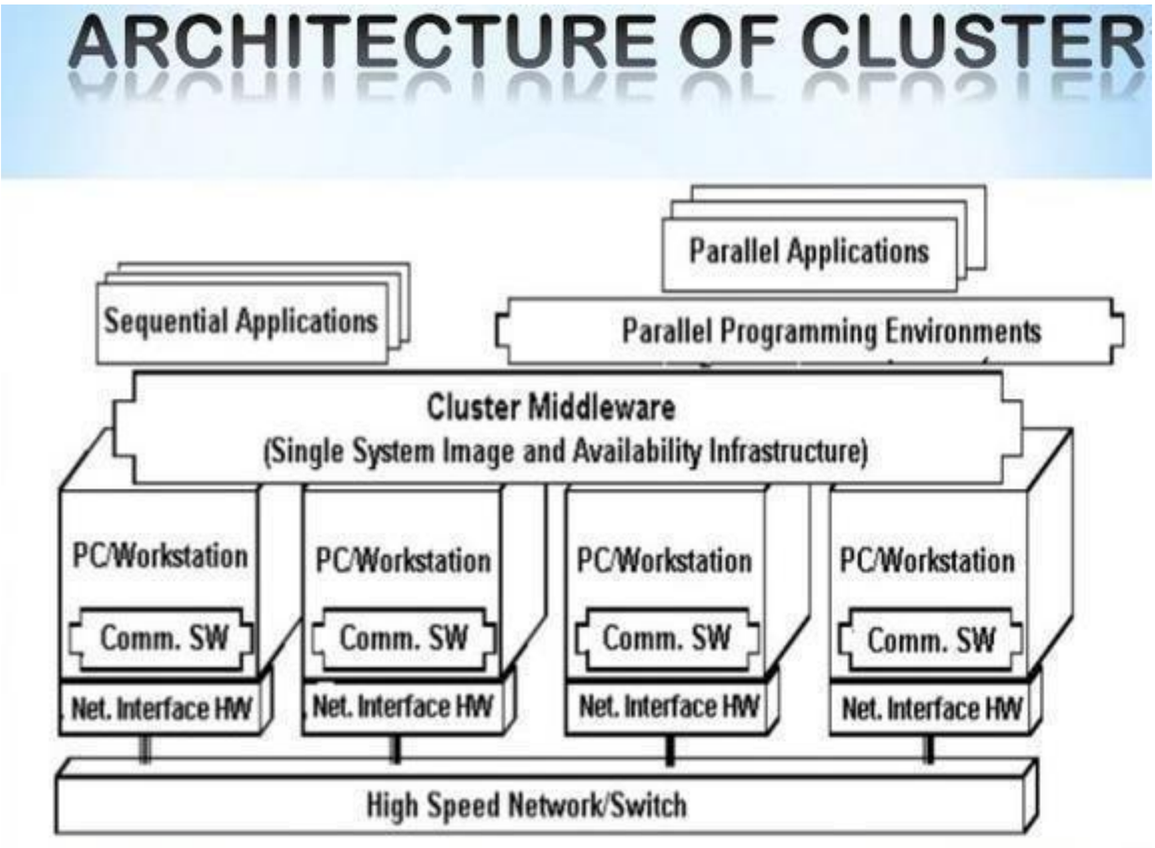


Fig4ClusterComputing

GRID COMPUTING

The computing resources in most of the organizations are under utilized but are necessaryforcertain operations. The idea ofgrid computing is to make use ofsuchnonutilized computing power bythe needy organizations, and therebythe return on investment (ROI) on computing investments can be increased. Thus, grid computing is a networkofcomputing or processor machines managed witha kind of software such as middleware, inordertoaccessandusetheresourcesremotely.Themanaging activityof grid resources through the middleware is called *grid services*. Grid services provide accesscontrol, security, access to data including digital libraries and databases, and access to large-scale interactive and long-termstorage facilities.

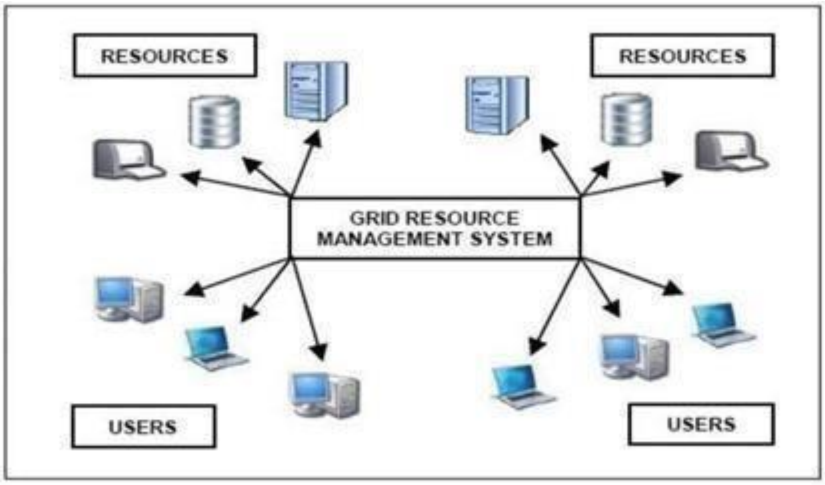


Fig5 Grid Computing

Grid computing is popular for the following reasons:

1) Its ability to make use of unused computing power, and thus, it is a cost- effective solution (reducing investments, onlyrecurring costs)
2) Asawaytosolveproblemsinlinewithany HPC-basedapplication
3) Enables heterogeneous resources of computers to work cooperatively and collaboratively to solvea scientific problem
4) Researchers associate theterm *grid* to the wayelectricity is distributed in municipalareas for the common man. In this context, the difference between electrical power grid and grid computing is worthnoting (Table 1.1).

CLOUD COMPUTING

The computing trend moved toward cloud from the concept of grid computing, particularly when large computing resources are required to solve a single problem, using the ideas of computing powerasa*utility*andother alliedconcepts. However,thepotentialdifference betweengridandcloud is that grid computing supports leveraging several computers in parallel to solve a particular application, while cloud computing supports -leveraging multiple resources, including computing resources, to deliver a unified *service* to the end user.

In cloud computing, the IT and business resources, such as servers, storage, network, applications, and processes, can be dynamicallyprovisioned to the userneeds and workload.

In addition, while a cloud can provision and support a grid, a cloud can also support non grid environments, suchas athree-tier webarchitecturerunning ontraditional or Web2.0 applications.

BIO COMPUTING

Bio computing systems use the concepts of biologically derived or simulated molecules (ormodels) that perform computational processes in order to solve a problem. The biologically derived models aid instructuring thecomputer programs thatbecome part ofthe application.

Bio computing provides the theoretical background and practical tools for scientists to explore proteins and DNA. DNAand proteins are nature's building blocks, but these building blocks are not exactly used as *bricks*; the function of the final molecule rather strongly depends on the *order* of these blocks. Thus, the bio computing scientist works on inventing the *order* suitable for various applications mimicking biology. Bio computing shall, therefore, lead to a betterunderstanding oflife and the molecularcauses ofcertaindiseases.

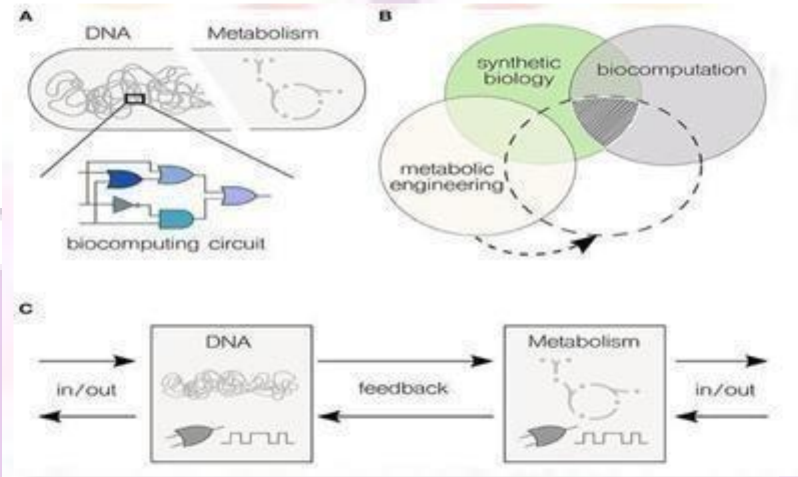


Fig 7 Bio Computing

MOBILE COMPUTING

In mobile computing, the processing (or computing) elementsare small(i.e., handheld devices) and the communication between various resources is taking place using wirelessmedia.

Mobile communication for voice applications (e.g., cellular phone) is widelyestablished throughout the world and witnesses a very rapid growth in all its dimensions including the increase in the number of subscribers of various cellular networks. An extension of this technology is the ability to send and receive data across various cellular networks using small devices such as smart phones. There can be numerous applications based on this technology; for example, video call or conferencing is one ofthe important applications that people prefer to use in place ofexisting voice (only) communications on mobile phones.

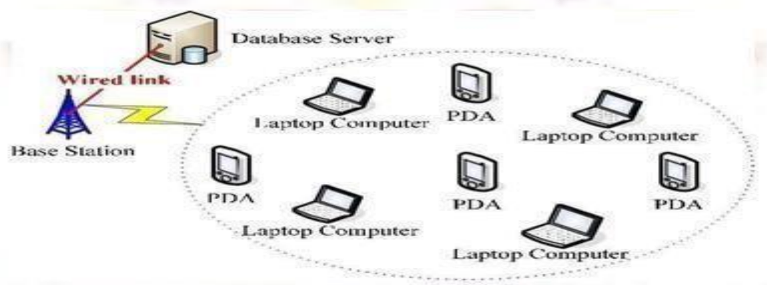


Fig8 Mobile Computing

Mobile communication for voice applications (e.g., cellular phone) is widelyestablished throughout the world and witnesses a very rapid growth in all its dimensions including the increase in the number of subscribers of various cellular networks. An extension of this technology is the ability to send and receive data across various cellular networks using small devices such as smart phones. There can be numerous applications based on this technology; for example, video call or conferencing is one ofthe important applications that people prefer to use in place ofexisting voice (only) communications on mobile phones.

Mobile computing–based applications are becoming very important and rapidly evolving with various technological advancements as it allows users to transmitdata from remote locations to other remoteor fixedlocations.

QUANTUM COMPUTING

Manufacturers of computing systems say that there is a limit for cramming more and more transistors into smaller and smaller spaces of integrated circuits (ICs) and thereby doubling the processing power about every18months.

This problem will have to be overcome by a new *quantum computing*–based solution, wherein the dependence is on quantum information, the rules that govern the subatomic world. Quantum computers are millions oftimes fasterthaneven our mostpowerfulsupercomputers today.

Since quantum computing works differently on the most fundamental level than the current technology, and although there are working prototypes, these systems have not so far proved to be alternatives to today's silicon-basedmachines.

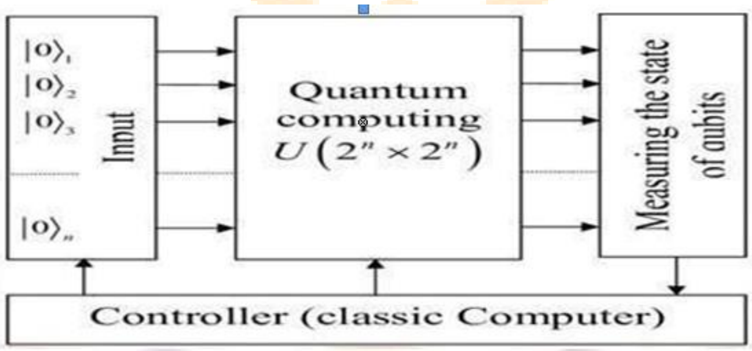


Fig9 Quantum Computing

OPTICAL COMPUTING

Optical computing system uses the photons in visible light or infrared beams, rather than electric current,to perform digital computations. An electric current flows at only about 10% of the speed of light.

This limits the rateat which data canbe exchanged over long distances and is oneofthe factors that led to the evolution ofoptical fiber.

By applying some of the advantages of visible and/or IR networks at the device and component scale, a computer can be developed that can perform operations 10or more times faster than a conventional electroniccomputer.

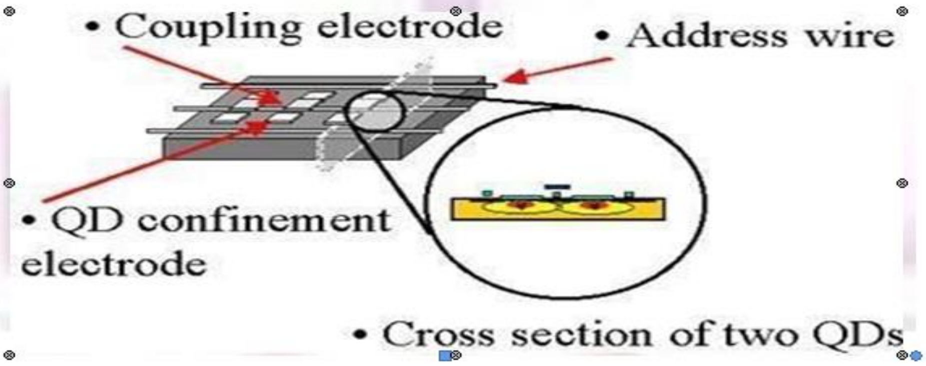


Fig10 Optical Computing

NANO COMPUTING

Nano computing refersto computing systemsthatare constructed fromnano scale components.The silicon transistors in traditional computers may be replaced by transistors based on carbon nano tubes. The successful realization of nano computers relates to the scale and integration of these nano tubes or components. The issues of scale relate to the dimensions of the components; they are, at most, a few nanometers inatleast two dimensions.

The issues of integration of the components are two fold:

1) The manufacture of complex arbitrary patterns may be economically infeasible
2) Nano computers may include massive quantities of devices.

Researchers are working on all these issues to bring nano computing a reality.

Fig11 Devices of Nano Computing

Fig11 Devices of Nano Computing

1.11 NETWORK COMPUTING

Network computing is a way of designing systems to take advantage of the latest technology and maximize its positive impact on business solutions and their abilityto serve their customers using a strong underlying network of computing resources. In any network computing solution, the client component of a networked architecture or application will be with the customer or clientor end user, and in modern days, they provide an essential set of functionality necessary to support the appropriate client functions at minimum cost and maximum simplicity. Unlike conventional PCs, theydo not need to be individually configured and maintained according to their intended use. The otherendoftheclient component inthe network architecture will be a typical *server* environment to *push* the services ofthe application to the clientend.

Almost all the computing paradigms that were discussed earlier are of this nature.Even in the future, if any one invents a totally new computing paradigm, it would be based on a networked architecture, without which itis impossible to realizethe benefits for anyend user.

SUMMARY

We are into a post-PC era, in which a greater number and a variety of computers and computing paradigms with different sizes and functions mightbe used everywhere and with every human being; so, the purpose of this chapter is to illustrate briefly theideas of all these computing domains, as most of these are ubiquitousand pervasivein its access and working environment.

CLOUD COMPUTING (23CY508)

UNIT-II

CLOUD COMPUTING FUNDAMENTALS

Cloud Computing Fundamentals: Motivation for Cloud Computing, The Need forCloud Computing, Defining Cloud Computing, Definition of Cloud computing, Cloud Computing Is a Service, Cloud Computing Is a Platform, Principles of Cloud computing, Five Essential Characteristics, Four Cloud Deployment Models

MOTIVATION FOR CLOUD COMPUTING

Let us review the scenario of computing prior to the announcement and availability of cloud computing: The users who are in need of computing are expected to invest money on computing resources such as hardware, software, networking, and storage; this investmentnaturally costs a bulk currency to the users as they have to buy these computing resources, keep these in their premises, and maintain and make it operational—all these tasks would add cost. And, this is a particularly true and huge expenditure to the enterprises thatrequire enormous computing power and resources, compared with classical academics and individuals.

On the other hand, it is easy and handy to get the required computing power and resources from some provider (or supplier) as and when it is needed and pay only for that usage. This would cost only a reasonable investment or spending, compared to the huge investment when buying the entire computing infrastructure.Thisphenomenoncanbe viewedas*capitalexpenditure*versus*operational expenditure*. As one can easily assess the huge lump sum required for capital expenditure (whole investment and maintenance for computing infrastructure) and compare it with the moderate or smallerlumpsum requiredforthehiringorgettingthecomputinginfrastructure only tothe tune of required time, and rest of the time free from that. Therefore, cloud computing is a mechanism of *bringing–hiring or getting the services of the computing power or infrastructure*toan organizational or individual level to the extent required and paying only for the consumed services. One can compare this situation with the usage of electricity (its services) from its producer- cum- distributor (in India,it is the state-/government-owned electricity boards that give electricity supply to all residencesand organizations) to houses or organizations; here, we do not generate electricity (comparable with electricity production– related tasks); rather, we use it only to tune up our requirements in our premises, such as for our lighting and usage of other electrical appliances, and pay as per the electricity meter readingvalue.

Therefore, cloud computing is needed in getting the services ofcomputing resources. Thus, one can say as a one-line answer to the need for cloud computing that it eliminates a large computing investment without compromising the use of computing at the user level at an operational cost. Cloud computing is veryeconomicaland saves a lot of money. A blind benefit of this computing is that even if we lose our laptop or due to some crisis our personal computer—and the desktop system—gets damaged, stillour dataand files will staysafe and secured asthese are not inourlocal machine (but remotely located at the provider's place— machine).

In addition, one can think to add security while accessing these remote computing resources as depictedin Figure 2.1.

Figure2.1 shows several cloud computing applications.

The *cloud* represents the Internet-based computing resources, and the accessibility is through some

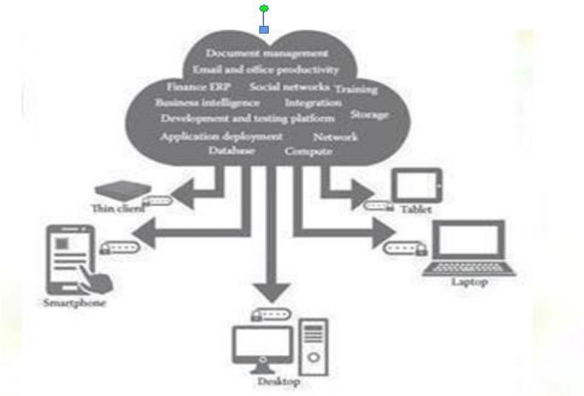


FIGURE 2.1
Cloud computing

Cloud computing secure support of connectivity. It is a computing solution growing in popularity, especially among individuals and small- and medium- sized companies (SMEs). In the cloud computing model, an organization's core computer power resides offsite and is essentially subscribedto rather than owned.

Thus, cloud computing comes into focus and much needed only when we think about what computing resources and informationtechnology(IT) solutions are required.

This need catersto awayto increase capacityor add capabilities onthe flywithout investing innew infrastructure,training newpersonnel,orlicensing newsoftware.Cloudcomputingencompassesthe subscription-based or pay-per-use service model of offering computing to end users or customers over the Internetand thereby extending the IT's existing capabilities.

THE NEED FOR CLOUD COMPUTING

The main reasons for the need and use of cloud computing are convenience and reliability. In the past, if we wanted to bring a file, we would have to save it to a Universal Serial Bus (USB) flash drive, external hard drive, or compact disc (CD) and bring that device to a different place. Instead, saving a file to the cloud (e.g., use of cloud application Drop box) ensures that we will be able to access it with anycomputer that has an Internet connection. The cloud also makes it much easier to sharea filewithfriends, makingitpossibleto collaborateovertheweb.

While using the cloud, losing our data/file is much less likely. However, just like anything online, there is always a risk that someone maytryto gain access to our personaldata.

It is important to choose an access control with a strong password and pay attention to any privacy settingsfor the cloud service thatwe are using.

DEFINING CLOUD COMPUTING

In the simplest terms, cloud computing means storing and accessing data and programs over the Internet from a remote location or computer instead of our computer's hard drive. This so called *remote location* has several properties such as scalability, elasticity etc., which is significantly different from a simple remote machine. The cloud is just a metaphor for the Internet. When we store data on or run a program from the local computer's hard drive that is called local storage and computing. For it to be considered*cloudcomputing*, weneed to access our dataor programs over the Internet. The end resultis the same; however, with an online connection, cloud computing can be done anywhere,anytime, and byanydevice.

NIST DEFINITION OF CLOUD COMPUTING

The formal definition of cloud computing comes from the National Institute of Standards and Technology (NIST): "Cloud computing is a model for enabling ubiquitous, 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. This cloud model is composed of five essential characteristics, three service models, and four deployment models. It means that the computing resourceor infrastructure—be it server hardware, storage, network, or applicationsoftware.

All available from the cloud vendor or provider's site/premises, can be accessible over the Internet fromanyremote locationand byanylocalcomputing device. Inaddition,- the usage or accessibility is to cost onlyto the levelof usage to the customers based ontheir needs and demands, also known as the *pay-as-you-go* or *pay-as-per-use* model. If the need is more, more quantum computing resources are made available (provisioning- with elasticity) by the provider. Minimal management effort implies thatat the customer's side.

The maintenance ofcomputing systems is veryminimalas theywill have to look atthese tasks only fortheir localcomputingdevicesused foraccessingcloud- basedresources, notforthosecomputing resources managed at the provider's side. Details of five essential characteristics, three service - models, and four deployment models are provided in the 5-4-3 principles in Section 2.3. Many vendors, pundits, and experts refer to NIST, and both the International Standards Organization (ISO)andthe InstituteofElectrical and Electronics Engineers (IEEE) back the NIST definition.

Now, let ustryto defineand understand cloud computing fromtwoother perspectives—asaservice and a platform—in thefollowing sections.

CLOUD COMPUTING IS A SERVICE

The simplest thing that any computer does is allow us to store and retrieve information.We can store our family photographs, our favorite songs, or even save movies on it, which is also the most basic service offered by cloud computing.

Let us look at the example of a popular application called *Flickr* to illustrate the meaning of this section.

While Flickr started with an emphasis on sharing photosand images, it hasemerged asagreat place to store those images. In manyways,it is superior to storing theimages on your computer:

First, Flickr allows us to easilyaccess ourimages no matterwhere weareorwhattype ofdevice we areusing. Whilewe might uploadthephotosofour vacationfromour home computer, later, wecan easilyaccess themfromourlaptop attheoffice. Second, Flickr lets us share the images. There is no need to burn them to a CD or save them on a flash drive. We can just send someone our Flickr address to share these photosor images.

Third, Flickr provides data security. By uploading the images to Flickr, we are providing ourselves with data security by creating a backup on the web. And, while it is always best to keep a local copy—either on a computer, a CD, or a flash drive— the truth is that we are far more likelyto lose the images that we store locallythan Flickris of losing our images.

CLOUD COMPUTING IS A PLATFORM

The World Wide Web(WWW) canbe considered as the operating system for allour Internet-based applications. However, one has to understand that we will always need a local operating system in ourcomputer to access web-based applications.

The basic meaning of the term *platform* is that it is the support on which applications run or give resultstotheusers. For example, Microsoft Windows isaplatform. But, aplatformdoes not haveto be an operating system. Java is a platform even though it is not an operating system.

Through cloud computing, the web is becoming a platform. With trends (applications) such as Office 2.0,more and more applications that were originally available on desktop computers are now being converted into web–cloud applications. Word processorslike Buzzword and office suites like Google Docs are now available in the cloud as their desktop counter-parts. Allthese kinds of trends in providing applications via the cloud are turning cloud computing into a platform or to act as a platform.

PRINCIPLES OF CLOUD COMPUTING

The 5-4-3 principles put forth by NIST describe (a) the five essential characteristic features that promote cloud computing, (b) the four deployment models that are used to narrate the cloud computing opportunities for customers while looking at architectural models, and (c) the three important and basic service offering models ofcloud computing.

FIVE ESSENTIAL CHARACTERISTICS

Cloud computing has five essential characteristics, whichare shown in Figure 2.2. Readers can note the word *essential*, which means that if any of these characteristics is missing, then it is not cloud computing:

***On-demand self-service*:** A consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service's provider.

***Broad network access*:** Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, laptops, and personaldigital assistants [PDAs]).

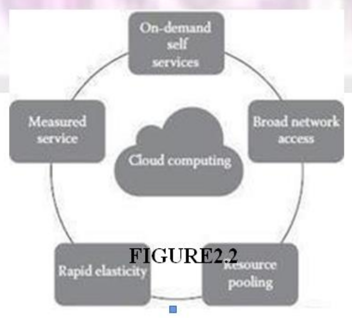


FIGURE2.2

***Elastic resource pooling*:** The provider's computing resources are pooled to serve multiple consumers using a multitenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. There is a sense of location independence in that the customer generally has no control or knowledge over the exact location of the provided resources but may beable to specify the location at a higherlevel of abstraction (e.g., country, state, or data center).

Examples of resources include storage, processing, memory,and network bandwidth.
Rapidelasticity**:** Capabilities can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out and rapidly released to quickly scale in.Totheconsumer, thecapabilitiesavail- able forprovisioningoftenappeartobeunlimited andcanbepurchased inanyquantityat anytime. ***Measured service*****:** Cloud systems automaticallycontroland optimize resource use byleveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing,bandwidth,and active user accounts).Resource usage can be monitored, controlled, and reported providing transparency for boththe provider and consumer ofthe utilized service.

FOUR CLOUD DEPLOYMENT MODELS

Deployment models describe the ways with which the cloud services can be deployed or made available to its customers, depending on the organizational structure and the provisioning location. One can understand it in this manner too: cloud (Internet)- based computing resources—that is, the locations where data and services are acquired and provisioned to its -customers— can take various forms. Four deployment models are usuallydistinguished, namely, public, private, community, and hybrid cloud service usage:

1) ***Private cloud*****:** The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated bythe organization,a third party.

   Some combination of them,and it may exist on or off premises.

2) ***Public cloud*****:** The cloud infrastructureis provisioned for openuse bythe generalpublic. It may be owned, managed, and operated by a business, academic, or government organization, or some combinationofthem. It exists onthe premises ofthe cloud provider.
3) ***Community cloud*****:** The cloud infrastructure is shared by several organizations and supports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be managed by the organizations or a third party and may exist on premise or offpremise.
4) ***Hybrid cloud*****:** The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities butare bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud burstingfor load balancing between clouds).

THREE SERVICE OFFERING MODELs

The three kinds of services with which the cloud-based computing resources are available to end customers are as follows: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). It is also known as the service–platform– infrastructure (SPI) modelofthe cloud andis shown in Figure 2.3.

1) **SaaS**is a software distribution model in which applications (software, which is one of the most important computingresources) arehostedbyavendororserviceprovider and madeavailable tocustomers overa network,typicallythe Internet.

2) **PaaS**is a paradigm for delivering operating systems and associated services (e.g., computer aided software engineering [CASE] tools, integrated development environments [IDEs] for developing software solutions) over the Internet without downloads or installation.

3) **IaaS**involves outsourcing the equipment used to support operations, including storage, hardware, servers, and networking components.

Cloud SaaS: The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure, including network, servers, operating systems, storage, andeven individual application capabilities, with the possible exception of limited user-specific application configuration settings. The applications are accessible from various client devices through either a thin clientorthrough a webprogram.

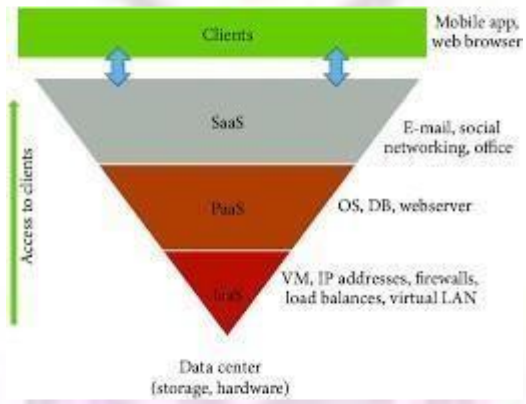


FIGURE2.3
SPI—service offering model of the cloud.

interface, such as a web browser (e.g., web-based e-mail), or a pro-gram interface. The consumer does not manage or control the underlying cloud infrastructure. Typical applications offered as a service include customer relationship management (CRM), business intelligence analytics, and online accounting software.

Cloud PaaS: The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programminglanguages,libraries, services, and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure but has control over the deployed applications and possibly configuration settings for the application-hosting environment. In other words, it is a packaged and ready- to-rundevelopmentoroperatingframework.

The PaaS vendor provides the networks, servers, and storage and manages the levels of scalability and maintenance. The client typically pays for services used. Examples of PaaS providers include Google App Engine and Microsoft Azure Services.

***Cloud IaaS*:** The capabilityprovided to the consumer is to provision processing, storage, networks, and other fundamentalcomputing resourcesona pay-per-use basis where he orshe is able to deploy andrunarbitrarysoftware, whichcanincludeoperating systemsandapplications. Theconsumerdoes not manage or control the underlying cloud infrastructure but has control over theoperating systems, storage, and deployed applications and possibly limited control of select networking components (e.g., host firewalls). The service provider owns the equipment and is responsible for housing, cooling operation, and maintenance. Amazon Web Services (AWS)is a popular example ofa large IaaS provider.

The major difference between PaaS and IaaS is the amount of control that users have. In essence, PaaS allows vendors to manage everything, while IaaS requires more management from the customer side. Generally speaking, organizations that already have a software packageor application for a specific purpose and want to install and run it in the cloud should opt to use IaaS instead of PaaS.

CLOUD ECOSYSTEM

Cloud ecosystem is a term used to describe the complete environment or sys-tem of interdependent components or entities that work together to enable and support the cloud services. To be more precise, the cloud computing's ecosystemis a complex environment that includes the description of everyitemorentityalongwiththeir interaction;the complex entities include the traditional elements ofcloud computing suchas software (SaaS), hardware (PaaS and/or IaaS),other infrastructure (e.g., network, storage), and also stakeholders like consultants, integrators, partners, third parties, and anythingintheir environments thathas a bearing ontheother.

In layman's terms, the cloud ecosystem describes the usage and value of each entity in the ecosystem,and when all the entities in the ecosystem are put together, users are now able to have an integrated suite made up ofthe best-of- breed solutions.

An example of this ecosystem can be a cloud accounting solution such as *Tally*; while this SaaS vendor focuses on their support for accounting and integrated payroll solutions, they can engage (collaborate) with any other third-party CSPs who could support additional features in the accounting software like reporting tools, dashboards, work papers, workflow, project management, and CRM, covering the majority of a client or customer firm's software needs. And, any other additionalrequirement that may be essentialwill likely be added bya partner joining the ecosystem inthe near future. Figure 2.4 illustratesthe idea ofa cloud ecosystem.

Fig2.4CloudEcosystem

REQUIREMENTS FOR CLOUD SERVICES

From the concepts illustrated in the earlier sections, one can understand that the cloud services or service offering models require certain featuresto be exhibited inorder to be considered as *services*. The following are the basic requirements for anything that can be considered as a service by the actorsofthe cloud computing ecosystem, whichcan be offered or provisioned throughthe cloud:

1) ***Multitenancy*:** Multitenancy is an essential characteristic of cloud systems aiming to provide isolationofthedifferent users of the cloud system (tenants) while maximizing resourcesharing. Itis expected that multitenancy be supported at various levels ofa cloud infra-structure. As an example, atthe application level, multitenancyis a featurethat allows a single instance of an application (say, database system) and leverages the economyofscale to satisfyseveralusers at the same time.
2) ***Service life cycle management*:** Cloud services are paid as per usage and can be started and ended at any time. Therefore, it is required that a cloud service support automatic service provisioning. In addition, metering and charging or billing settlement needs to be pro-vided for services that aredynamicallycreated, modified,and then released in virtualenvironments.
3) ***Security*:** The security of each individual service needs to be protected in the multitenant cloud environment;the users(tenants) also supporttheneeded secured services.
   Meaning that a cloud provides strict control for tenants' service access to different resources to avoidthe abuseofcloud resources andto facilitatethe management ofCSUs byCSPs.
4) ***Responsiveness*:** The cloud ecosystem is expected to enable early detection, diagnosis, and fixing ofservice-relatedproblems inorderto help the customersusethe servicesfaithfully.
5) ***Intelligent service deployment*:** It is expectedthatthe cloud enables efficient useofresources in service deployment, that is, maximizing the number of deployed services while minimizing the usage of resources and still respecting the SLAs. For example, the specificapplication characteristics (e.g., central processing unit [CPU]-intensive, input/ output [IO]-intensive) that can be provided by developers or via application monitoring may help CSPs in making efficient use of resources.
6) ***Portability*:** It is expected that a cloud service supports the portability of itsfeatures over various underlying resources and that CSPs should be able to accommodate cloud workload portability(e.g., VMportability) with limited service disruption.
7) ***Interoperability*:** It isexpectedto haveavailable well- documented and well- tested specificationsthat allowheterogeneoussystems incloudenvironmentsto worktogether.
8) ***Regulatoryaspects*:**Allapplicableregulationsshallberespected,includingprivacyprotection.
9) ***Environmentalsustainability*:** Akeycharacteristicofcloudcomputing isthecapabilityto access, through a broad network and thin clients.

On demand shared pools of configurable resources that can be rap-idly provisioned and released. Cloud computing canthenbe considered in itsessence asanICT energyconsumptionconsolidation model, supporting mainstream technologies aiming to optimize energy consumption (e.g., in data centers) and application performance. Examples of such technologies include virtualization and multitenancy.

10) ***Service reliability, service availability, and quality assurance*:** CSUs demand for their services end-to-end quality of service (QoS) assurance, high levels of reliability, and continuedavailability to theirCSPs.

11) ***Serviceaccess***: Acloud infrastructureisexpectedto provide CSUswithaccessto cloudservices from any user device. It is expected that CSUs have a consistent experience when accessing cloud services.

12) ***Flexibility***: It is expected that the cloud service be capable of supporting multiple cloud deploymentmodels and cloud service categories.

13) ***Accounting and charging***: It is expected that a cloud service be capable to support various accounting and chargingmodels and policies.

14) ***Massive data processing***: It is expected that a cloud supports mechanisms for massive data processing (e.g., extracting, transforming, and loading data). It is worth to note in this context that distributed and/or parallel processing systems will be used in cloud infrastructure deployments to provide large -scale integrated data storage and processing capabilities that scale with software-based fault tolerance.

The expected requirements for services in the IaaS category include the following:

1. Computing hardware requirements (including processing,memory,disk,network interfaces, and virtual machines)
2. Computing software requirements (including OS and other preinstalled software)
3. Storage requirements(including storage capacity)
4. Network requirements(including QoS specifications,such as bandwidth and traffic volumes)

The expected service requirements for services in the PaaS category include the following:

1) Requirements similar to those of the IaaS category
2) Deployment options of user-created applications(e.g.,scale-out options)
3) The expected service requirements for services in the SaaS category include the following:
4) Application-specific requirements(including licensing options)

Network requirements (including QoS specifications such as band-width and traffic volumes)

CLOUD APPLICATION

A cloud application is an application program that functions or executes in thecloud;the application can exhibit some characteristics of a pure desk-top application and some characteristics of a pure web-based application. A desktop application resides entirely on a single device at the user'slocation-(itdoesnot necessarilyhaveto beadesktopcomputer),and on the other hand, aweb applicationis stored entirely on a remote server and is delivered over the Internet through a browser interface.

Like desktop applications, cloud applications can provide fast responsiveness and can work offline. Like web applications, cloud applications need not permanently reside on the localdevice, but they canbeeasilyupdatedonline. Cloud applicationsare,therefore, under theuser'sconstant control, yet they need not always consume storage space on the user's computer or communications device. Assuming that the user has a reasonably fast Internet connection, a well-written cloud application offers all the interactivity of a desktop application along withthe portabilityofawebapplication.

A cloud application can be used with a web browser connected to the Internet.Now,it ispossible for the user interface portion of the application to existon the local device andfor the user to cache data locally, enabling full offline mode when desired. Also, a cloud application, unlike a web app, can be used in any sensitive situation where wireless devices—connectivity—are not allowed (i.e., evenwhen noInternet connection is availablefor some period).

An example of cloud application is a web-based e-mail (e.g., Gmail, Yahoo mail); inthis application, the user of the e-mail uses the cloud—all of the emails in their inbox are stored on servers at remote locations at the e-mailservice provider.

However, there are many other services that use the cloud in different ways. Here is yet another example: Dropbox is a cloud storage service that lets us easily store and sharefiles with other people and access files froma mobile device as well.

BENEFITS AND DRAWBACKS

One of the attractions of cloud computing is accessibility. If our applications and documents are in the cloud and are not saved on an office server, then we can access and use them at anytime, anywhere for our working, whether we are at work, at home, or even at a friend’s house. Cloud computing also enables precisely the right amount ofcomputing power and resources to be used for applications. Cloud computing vendors provide computing-related services as a bundleof computing power and parcel it out ondemand.

Customers can draw and make use as much or as little computing power as theyneed, being charged only for the usage time/computing power; accordingly, this scheme can save money. This also implies thatscalability is one ofthe cloud computing’s bigbenefits.

Whenwe need more computing power, cloud computing cangive instant access to exactlywhat we need. In the cloud model, an organization’s core computer power resides offsite and is essentially subscribed to rather than owned. There is no capital expenditure, only operational expenditure.

It also relieves us from the responsibility and costs of maintenance of the entire computing infrastructureand pushes allthese tothe cloud vendoror provider. The cloud also offers a new level of reliability. The*virtualization* technology enables a vendor’s cloud software to automatically move data from a piece of hardware that goes bad or is pulled offline to a section of the system or hardware that is functioning or operational.

Therefore,the client gets seam-less access to the data.Separate backup systems, with cloud disaster recovery strategies, provide another layer of dependability and reliability. Finally, cloud computing also promotes a *green* alternative topaper- intensive office functions.It is because it needs less computing hardware onpremise,and all computing-related tasks take place remotelywith minimal computing hard-ware requirementwiththe help oftechnological innovations such as virtualization and multitenancy.Another view point on the *green* aspect is that cloud computing can reduce the environmental impact of building, shipping, housing, and ultimately destroying (or recycling) Computer equipment asno one isgoing to own many such systems in their premises and managing the offices with fewer computers that consume less energy comparatively.

A consolidated set of points briefing the benefits of cloud computing can be as follows:

1) ***Achieve economies of scale*:** We can increase the volume output or productivity with fewer systems and therebyreduce the costper unit ofaproject or product.
2) ***Reduce spending on technology infrastructure*:** It is easy to access data and information with minimalupfront spending in a *pay-as-you-go* approach, inthe sense that the usage and payment are similar to an electricity meter reading inthe house, which is based ondemand.
3) ***Globalize the work force*:** People worldwide can access the cloud withI nternet connection.
4) ***Streamline business processes*:** It is possible to get more work done in less time with less resource.

5) ***Reduce capital costs*:** There is no need to spend huge money on hard-ware, software, or licensing fees.

6) ***Pervasive accessibility*:** Data and applications can be accessed anytime, anywhere, using any smart computing device,making our life somucheasier.

7) ***Monitor projects more effectively*:** It is possible to confine within budgetary allocations and can be ahead ofcompletion cycle times.

8) ***Less personnel training is needed*:** It takes fewer people to do more work on a cloud, with a minimal learning curve onhardware and soft-wareissues.

9) ***Minimize maintenance and licensing software*:** As there is no too much of on- premise computing resources, maintenance becomes simple and updates and renewals of software systems relyon the cloudvendor or provider.

10) ***Improved flexibility*:** It is possible to make fast changes in our work environment without serious issues atstake.

Drawbacks to cloud computing are obvious. The main point in this context is that if we lose our Internet connection, we have lostthe link to the cloud and thereby to the data and applications. There is also a concern about security as our entire working with data and applications depend on other's (cloud vendor or providers) computing power.

Also, while cloud computing supports scalability (i.e., quickly scaling up and down computing resources depending on the need), it does notpermit the control on these resources as these are not owned by the user or customer. Depending on the cloud vendor or provider, customers may face restrictions on the availability of applications, operating systems, and infrastructure options. And, sometimes, alldevelopment platforms maynot beavailable intheclouddue tothefactthatthecloud vendor may not aware of such solutions. A major barrier to cloud computing is the interoperability of applications, which is the ability of two or more applications that are required to support a business need to worktogether bysharing data and other business- related resources. Normally, this does not happen in the cloud as these applications may not be available with a single cloud vendor and two different vendors having these applications donot cooperate witheachother.

Cloud Computing Architecture and Management

Cloud Computing Architecture and Management:Cloud architecture, Layer, Anatomyofthe Cloud, Network Connectivity in Cloud Computing, Applications, on the Cloud, Managing the Cloud, Managing the Cloud Infrastructure Managing the Cloud application, Migrating Applicationto Cloud, Phases ofCloud Migration Approaches for Cloud Migration.

INTRODUCTION

Cloud computing issimilar toothertechnologies ina waythat it also hasseveralbasic concepts that one should learn before knowing its core concepts. There are several processes and components of cloud computing that need to be discussed. One of the topics of such prime importance is architecture. Architecture is the hierarchical view of describing a technology. This usually includes the components over which the existing technology is built and the components that are dependent on the technology. Another topic that is related to architecture is anatomy. Anatomy describes the core structure of the cloud. Once the structure of the cloud is clear, the network connections in the cloud and the details aboutthe cloud application need to be known. This is important asthe cloud is a completely Internet dependent technology. Similarly, cloud management discusses the important managementissues and ways inwhichthe current cloud scenariois managed.

It describes the way an application and infrastructure in the cloud are managed. Management is important because of the quality of service (QoS) factors that are involved in the cloud. These QoS factors formthe basis for cloud computing. Allthe services are givenbased onthese QoS factors.

Similarly, application migration to the cloud also plays a very important role. Not all applications can be directly deployed to the cloud. An application needs to be properly migrated to the cloud to be considered a proper cloud applicationthat will have allthe properties ofthe cloud.

3.1Cloudarchitecture

Cloud Computing, which is one of the demanding technology of the current time and which is givinga new shape to every organization by providing on demand virtualized services/resources. Starting from small to medium and medium to large, every organization use cloud computing services for storing information and accessing it from anywhere and any time only with the help of internet.

CloudComputingArchitecture:

The cloud architecture is divided into 2parts i.e.

1. Frontend
2. Backend

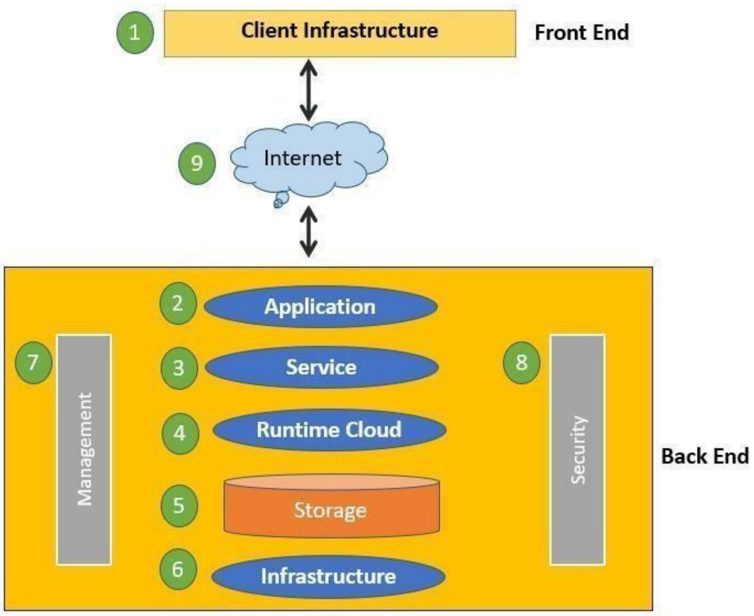


FIGURE3.1CloudArchitecture

Front end :

Frontend of the cloud architecture refers to the client side of cloud computing system. Means it contains all the user interfaces and applications which are used by the client to access the cloud computing services/resources.For example, use of a web browser to access the cloud platform.

- **Client Infrastructure** – Client Infrastructure is a part of the frontend component. It contains the applications and user interfaces which are required to access the cloud platform.
- Inotherwords,it provides a GUI(Graphical User Interface) to interact with the cloud.

Backend:

Backend refers to the cloud itself which is used bythe service provider. It contains the resources as well as manages the resources and provides security mechanisms. Along with this, it includes huge storage,virtual applications,virtual machines,traffic control mechanisms,deployment models, etc.

1.Application–

Application in backend refers to a software or platformto which client accesses. Means it provides the service in backend as per the client requirement.

2.Service–

Service in backend refers to the major three types ofcloud based services like SaaS, PaaS andIaaS.Also manages which type of service the user accesses.

3. RuntimeCloud-

Runtime cloud in backend provides the execution and Runtime platform/environment to the Virtual machine.

4.Storage–

Storage in back end provides flexible and scalable storage service and management of stored data.

5.Infrastructure–

Cloud Infrastructure in backend refers to the hardware and software components of cloud like it includes servers, storage, network devices, virtualization software etc.

6.Management–

Management in backend refers to management of backend components like application, service, runtime cloud, storage, infrastructure, and other security mechanisms etc.

7.Security–Security in backend refers to implementation of differentsecurity mechanisms in the backend for secure cloud resources, systems, files, and infrastructure to end-users.

8. Internet –
Internet connection acts as the medium or a bridge between frontend and backend and establishes the interaction and communication between frontend and backend.

9. Database– Database inbackend refers to provide database for storing structured data, such as SQL and NOSQL databases. Example of Databases services include Amazon RDS,Microsoft Azure SQL database and Google CLoud SQL.

10. Networking– Networking in backend servicesthat provide networking infrastructure for application in the cloud, such as load balancing,DNS and virtualprivate networks.

11. Analytics–Analyticsinbackendservicethatprovidesanalyticscapabilitiesfordatainthe cloud,such as warehousing, business intelligence and machine learning.

Benefits of Cloud Computing Architecture:
- Makes overall cloud computing system simpler.
- Improves data processing requirements.
- Helps in providing high security.

CLOUD Layers

Any technological modelconsists ofan architecture based on which the model functions, which is a hierarchical view of describing the technology. The cloud also has an architecture that describes its working mechanism. It includes the dependencies on which it works and the components that work over it. The cloud is a recent technology that is completely dependent on the Internet for its functioning. Figure 3.2 depicts the layers.

The cloud architecture can be divided into four layers based onthe access of the cloud bythe user. They are as follows.

LAYER1 (USER/CLIENT LAYER)

This layer is the lowest layer in the cloud architecture.All the users or client belong to this layer. This is the place where the client/user initiates the

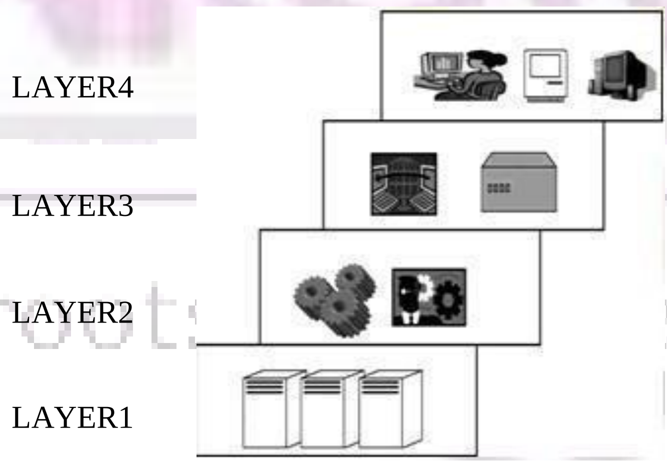


FIGURE 3.2 Cloud Layers.

Connection to the cloud.The client can be any device such as a thin client, thick client,or mobile or any handheld device that would support basic functionalities to access a web application. The thin client here refers to a device that is completely dependent on some other system for its complete functionality. In simple terms, they have very low processing capability. Similarly, thick clients are general computers that have adequate processing capability. They have sufficient capability for independent work. Usually, a cloud application can be accessed in the same way as a web application.But internally, the properties of cloud applications are significantly different. Thus, this layer consists ofclientdevices.

LAYER2 (NETWORK LAYER)

This layer allowsthe usersto connect tothe cloud.The whole cloud infra- structure isdependent on this connection where the services are offered to the customers.

This is primarily the Internet in the case of a public cloud. The public cloud usually exists in a specificlocationand the user would not knowthe locationas it is abstract. And, the public cloud can be accessed allover the world. Inthe case ofa private cloud,the connectivitymay be pro-vided bya local area network (LAN).Even in this case, the cloud completely depends on the network that is used. Usually, when accessing the public or private cloud, the users require minimum bandwidth, which is sometimes defined by the cloud providers. This layer does not come under the preview of service-level agreements (SLAs), that is, SLAs do not take into account the Internet connection betweenthe user and cloud for qualityofservice (QoS).

LAYER3(CLOUDMANAGEMEN TLAYER)

This layer consists of software that are used in managing the cloud. The software can be a cloud operating system (OS), a software that acts as an interface between the datacenter(actual resources) and the user, or a management soft- ware that allows managingresources.These software usually allow resource management (scheduling, provisioning, etc.), optimization (server consolidation, storage workload consolidation),and internalcloud governance.

This layer comes under the purview ofSLAs, that is, the operations taking place inthis layer would affect the SLAs that are being decided upon between the users and the service providers. Any delay inprocessing or anydiscrepancyin ser-vice provisioningmay lead toanSLAviolation.

As per rules, anySLA violationwould result ina penaltyto be givenbythe service provider. These SLAs are for both private and public clouds Popular service providers are Amazon Web Services (AWS) and Microsoft Azure for public cloud. Similarly, OpenStack and Eucalyptus allow private cloud creation, deployment, and management.

LAYER4(HARDWARE RESOURC ELAYER)

Layer 4 consistsofprovisions for actual hardware resources.Usually, inthe case ofa public cloud, a data center is used in the back end. Similarly, in a private cloud, it can be a data center, which is a huge collection of hardware resources interconnected to each other that is present in a specific location or a high configuration system. This layer comes under the purview of SLAs. This is the most important layer that governs the SLAs. This layer affects the SLAs most in the case of data centers. Whenever a user accesses the cloud, it should be available to theusers as quickly as possible and should be within the time that is defined by the SLAs. As mentioned, if there is any discrepancyinprovisioning the resourcesor application, the service provider has to paythe penalty. Hence, the data center consists of a high-speed network connection and a highly efficient algorithm to transfer the data from the data center to the manager.

There can be a number of data centers for a cloud, and similarly, a number of clouds can share a data center.
Thus, this is the architecture of a cloud. The layering is strict, and for any cloud application, this is followed. There can be a little loose isolation between layer 3 and layer 4 depending onthe waythe cloud is deployed.

ANATOMY OF THE CLOUD

Cloud anatomy can be simply defined as the structure of the cloud. Cloud anatomy cannot be considered the same as cloud architecture. It may not include any dependency on which or over which the technologyworks,

FIGURE 3.3 Anatomy of the Cloud.

where as architecture wholly defines and describes the technology over which it is working. Architecture is a hierarchical structural view that defines the technology as well as the technology over which it is dependent or/and the technology that are dependent on it. Thus, anatomy can be considered as a part ofarchitecture. The basic structureofthe cloud is described in Figure 3.2, which can beelaborated, and minute structuraldetails can be given.
Figure 3.2 depicts the most standard anatomythat is the base for the cloud. It depends on the person to choose the depth of description of the cloud. Adifferentview ofanatomy is given by Refs.[1,2].

There are basically five components of the cloud:

Application: The upper layer is the application layer.In this layer, any applications are executed.
Platform: This component consists of platforms that are responsible for the execution of the application. This platform is between the infrastructure and the application.
Infrastructure: The infrastructure consists ofresources over whichthe other components work. This provides computational capabilityto the user.
Virtualization: Virtualization is the process of making logical components of resources over the existing physical resources. The logical components are isolated and independent, which form the infrastructure.
Physicalhardware:The physical hardware is provided by server and storage units.

NETWORK CONNECTIVITY IN CLOUD COMPUTING

Cloud computing is a technique of resource sharing where servers, storage, and other computing infrastructure in multiple locations are connected by networks. In the cloud, when an application is submitted for its execution, needy and suitable resources are allocated from this collection of resources; as these resources are connected via the Internet, the users get their required results. For manycloud computing applications, network performance will be the key issue to cloud computing performance.

Since cloud computing has various deployment options, we now consider the important aspects related to the cloud deployment models and their accessibility from the viewpoint of network connectivity.

PUBLIC CLOUD ACCESS NETWORKING

In this option, the connectivity is often through the Internet, though some cloud providers may be able to support virtualprivate networks (VPNs) for customers. Accessing public cloud services will always create issues related to security, which in turn is related to performance. One ofthe possible approaches toward the support of security is to promote connectivity through encrypted tunnels, so that the information may be sent via secure pipes on the Internet. This procedure will be an overheadin the connectivity, and using it willcertainly increase delayand may impact performance. If we want to reduce the delay without compromising security, then we have to select a suitable routing method such as the one reducing the delay by minimizing transit *hops* in the end-to- end connectivity between the cloud provider and cloudconsumer.

Since the end-to - end connectivity support is via the Internet, which is a complex federation of interconnected providers (known as Internet service providers [ISPs]),one has to look at the options ofselecting the path.

PRIVATE CLOUD ACCESS NETWORKING

In the private cloud deployment model, since the cloud is part of an organizational network, the technologyand approaches are localto the in-house network structure. This may include an Internet VPN or VPN service from a network operator. If the application access was properly done with an organizational network— connectivity in a *precloud* configuration—transition to private cloud computing will notaffect the access performance.

INTRA CLOUD NETWORKING FOR PUBLIC CLOUD SERVICES

Another network connectivity consideration in cloud computing is intra-cloudnetworkingfor public cloud services. Here, the resources of the cloud provider and thus the cloud service to the customer arebasedontheresourcesthat aregeographicallyapart fromeachother but stillconnected via the Internet.

Public cloud computing networks are internal to the service provider and thus not visible to the user/customer; however, the securityaspects ofconnectivity Another issue to look for is the QoS in the connected resources worldwide. Most of the performance issues and violations from these are addressed in the SLAs commercially.

PRIVATE INTRA CLOUD NETWORKING

The most complicated issue for networking and connectivity in cloud computing is private intracloudnetworking. What makes this particular issue so complex is that it depends on how much intracloud connectivity is associated withthe applications being executedinthis environment.

Private intra-cloud networking is usually supported over connectivitybetweenthe major data center sites owned by the company. At a minimum, all cloud computing implementations will rely on intracloud networking to link users with the resource to which their application was assigned. Once the resource link-age ismade, the extent to which intracloud networking is used depends onwhether the application is componentized based on *service-oriented architecture (SOA)* or not, among multiple systems. If the principle of SOA is followed, then traffic may movebetween components ofthe application, as well as between the application and the user.

The performance of those connections will then impact cloudcomputingperformanceoverall.Here too, the impact of cloud computing performance is the differences that exist between the current application and the networkrelationships withthe application.
There are reasons to consider the networks and connectivity in cloud computing with newer approaches as globalization and changing network requirements, especially those related to increased Internet usage, are demanding more flexibility in the network architectures of today's enterprises. Howaretheserelatedto us?The answers are discussedlater.

NEW FACETS IN PRIVATE NETWORKS

Conventional private networks have been architected for on-premise applications and maximum Internet security. Typically, applications such as e-mail, file sharing, and *enterprise resource planning*(ERP)systemsaredeliveredtoon- premise-based servers ateachcorporate datacenter.

Increasingly today, software vendors are offering Software as a Service (SaaS) as an alternative for their software support to the corporate offices,which brings morechallenges in the access and usage mechanisms of software from data center servers and in the connectivity of network architectures. The traditional network architecture for these global enterprises was not designed to optimize performance for cloud applications, nowthat manyapplications including mission- critical applications are transitioning (moving) fromon-premise based to cloud based, wherein the network availability becomes as mission critical as electricity: the business cannotfunction if itcannot access applications suchas ERP and e- mail.

PATH FOR INTERNET TRAFFIC

The traditional Internet traffic through a limited set of Internet gateways poses performance and availability issues for end users who are using cloud-based applications. It can be improvedif a more widely distributed Internet gateway infrastructure and connectivity are being supported for accessing applications, as they will provide lower-latency access to their cloud applications. As the volume of traffic to cloud applications grows, the percentage of the legacy network's capacity in terms of traffic to regional gateways increases. Applications such as video conferencing would hog more bandwidth while mission-critical applications such as ERP will consume less bandwidth, and hence,onehasto plana correct connectivityand pathbetweenproviders and consumers.

APPLICATIONS ON THE CLOUD

The power of a computer is realized through the applications. There are several typesof applications. The first type of applications that was developed and used was a stand-alone application.Astand-alone application is developed-toberunonasinglesystemthatdoesnotusenetworkforitsfunctioning.These stand-alone systems use only the machine in which they are installed. The functioning of these kinds of systems is totallydependent onthe resourcesorfeatures available within the system. These systems do not needthe dataor processing powerofother systems;theyare self-sustaining.

But as the time passed, the requirements of the users changed and certain applicationswererequired, which could be accessed by other users away from the systems. This led to the inception ofwebapplication.

The web applications were different from the stand-alone applications in many aspects. The main difference wasthe client server architecturethat was followed bythe webapplication. Unlike stand- alone applications, these systems were totallydependent onthe network for its working. Here, there are basically two components, called as the client and the server. The server is a high-end machine that consists of the web application installed. This web application is accessed from other client systems. The client can reside anywhere in the network. It can access the web application through the Internet. This type of application was very useful, and this is extensively usedfromitsinception.

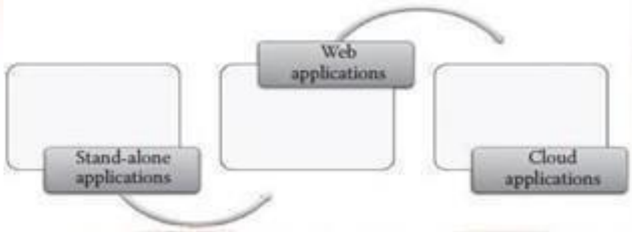


FIGURE3.3 Computer application evolution

Though this application is much used, there are short comings as discussed in the following:

1) The web application is not elastic and cannot handle very heavy loads, that is, it cannot serve highly varyingloads.
2) The web application is not multitenant.

The web application does not provide a quantitative measurement of the services that are given to the users, thoughtheycan monitor the user.

3) Thewebapplicationsareusuallyinoneparticularplatform.
4) The web applications are not provided on a pay-as- you-go basis; thus, a particular service is given to the user for permanent or trial use and usually the timings of user access cannot be monitored.

Due to its non elastic nature,peak load transactions cannot be handled.

Primarily to solve the previously mentioned problem, the cloud applications were developed. Figure depicts the improvements inthe applications.

The cloud as mentioned can be classified into three broad access or ser-vice models, Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). Cloud application in general refers toa SaaS application.

A cloud application is different from other applications; they have unique features. A cloud application usually can be accessed as a web application but its properties differ. According to NIST[3],the featuresthat make cloud applications unique are described inthe following (Figure 3.4 depicts the features of a cloud application):

Multitenancy: Multitenancy is one of the important properties of cloud that make it different from other types of application in which the software can be shared by different users with full independence-. Here, independence refers to logical independence.

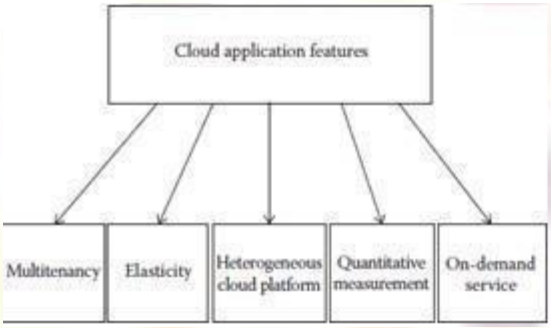


FIGURE3.4 Features of cloud.

Each user will have a separate application instance and the changes in one application would not affect theother. Physically, thesoft-wareisshared and is not independent.

The degree ofphysical isolation is very less. The logical independence is what is guaranteed. There are no restrictions in the number of applications being shared. The difficulty in providing logical isolation depends on the physical isolation to a certain extent. If an application is physically too close, then it becomes difficult to provide multitenancy. Web application and cloud application are similar as the users use the same way to access both. Figure 3.5 depicts a multitenant application where severalusers share the same application.

Elasticity: Elasticity is also a unique property that enables the cloud to serve better. According to Herbst et al. [4], elasticity can be defined as the degree to which a system is able to adapt to workload changes by provisioning and deprovisioning resources in an autonomic manner such that at each point in time, the available resources match the current demand as closely as possible. Elasticityallowsthe cloud providersto efficientlyhandle the number ofusers.

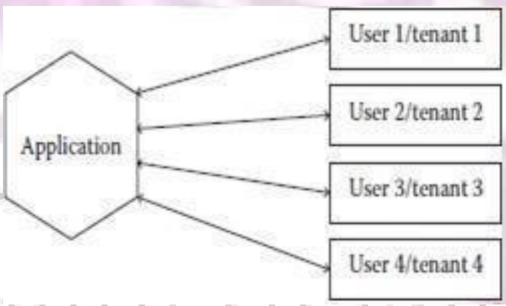


FIGURE3. Multitenancy.

In addition to this, it supports the rapid fluctuation of loads, that is, the increase or decrease in the numberofusers and their usage can rapidlychange.

Heterogeneous cloud platform: The cloud platform supports heterogeneity, wherein any type of application can be deployed in the cloud. Because of this property, the cloud is flexible for the developers, which facilitates deployment. The applications that are usually deployed can be accessedbythe users using a web browser.

***Quantitative measurement*:** The services provided can be quantitatively measured. The user is usually offered services based on certain charges. Here, the application or resources are given as a utility on a pay-per-use basis. Thus, the use can be monitored and measured. Not only the services are measureable,but also the linkusageandseveralotherparametersthat support cloudapplications can be measured. This propertyof measuring the usage is usually not available in a webapplication andis a uniquefeature for cloud-based applications.

***On-demand service*:** The cloud applications offer service to the user, on demand, that is, whenever the user requires it. The cloud service would allow the users to access web applications usually without anyrestrictions ontime, duration, and type ofdevice used.

The previously mentioned properties are some of the features that make cloud a unique application platform. These properties mentioned are specific to the cloud hence making it as one of the few technologies that allows application developers to suffice the user's needs seamlessly without any disruption.

MANAGING THE CLOUD

Cloud management isaimedat efficientlymanagingthecloudso asto maintaintheQoS.It isoneof the prime jobs to be considered. The whole cloud is dependent on the way it is managed. Cloud managementcan be dividedinto two parts:

Managing the infrastructure of the cloud & Managing the cloud application.

MANAGING THE CLOUD INFRASTRUCTURE

The infrastructure of the cloud is considered to be the backbone of the cloud. This component is mainly responsible for the QoS factor. If the infrastructure is not properly managed, then the whole cloud can fail and QoS would be adversely affected. The core of cloud management is resource management. Resource management involves several internal tasks such as resource scheduling, provisioning, and load balancing. These tasks are mainly man-aged by the cloud service provider's core software capabilities such as the cloud OS that is responsiblefor providing services to the cloud and that internally controls the cloud. A cloud infrastructure is a very complex system that consists ofa lot ofresources. These resources are usuallysharedbyseveralusers.

Poor resource management may lead to several inefficiencies in terms ofperformance,functionality, and cost. If a resource is not efficiently managed, theperformance of the whole system is affected.

Performance isthe most important aspectofthe cloud, because everything inthe cloud isdependent on the SLAs and the SLAs can be satisfied only if performance is good. Similarly, the basic functionality of the cloud should always be provided and considered at any cost. Even if there is a small discrepancy in providing the functionality, the whole purpose of maintaining the cloud is futile.Apartially functionalcloud would notsatisfytheSLAs.

Lastly, the reason for which the cloud was developed was cost. The cost is a veryimportantcriterion as far as the business prospects of the cloud are concerned. On the part of the service providers, iftheyincur less cost for managingthe cloud,thentheywouldtrytoreducethecost so as to get astronguserbase. Hence, a lotofuserswouldusethe services, improvingtheirprofit margin. Similarly, if the cost of resource management is high, then definitely the cost of accessing the resources would be highand there is never a lossy business fromanyorganization and so the service provider would not bearthe cost and hence the users have to paymore. Similarly, thiswould prove costly for service providers as they have a high chance of losing a wide user base, leading to onlya marginalgrowthinthe industry. And, competing with its industryrivals would become a big issue. Hence, efficientmanagementwith lesscost is required.

At a higher level, other than these three issues, there are few more issues that depend on resource management. These are power consumption and optimization of multiple objectives tofurther reduce the cost. To accomplish these tasks, there are several approaches followed, namely, consolidationofserver and storage workloads. Consolidationwould reduce the energyconsumption and in some cases would increase the performance of the cloud. According to Margaret Rouse [5], server consolidation by definition is an approach to the efficient usage ofcomputer server resources inorder to reducethetotalnumber ofservers or serverlocations thatanorganizationrequires.

The previously discussed prospects are mostly suitable for IaaS. Similarly, there are different management methods that are followed for different types of service delivery models. Each of the type has its own way of management. All the management methodologies are based on load fluctuation. Load fluctuation isthe pointwherethe workloadofthe systemchanges continuously.

This is one of the important criteria and issues that should be considered forcloud applications. Load fluctuation can be divided into two types: predictable and unpredictable. Predictable load fluctuations are easy to handle. The cloud can be preconfigured for handling such kind of fluctuations. Whereas unpredictable load fluctuations are difficult to handle, ironicallythis is one of the reasons why cloudis preferredbyseveralusers.

This is as far as cloud management is concerned. Cloud governance is another topic that is closely related to cloud management. Cloud governance is different from cloudmanagement. Governance ingeneralis a terminthe corporateworld that generallyinvolves the process ofcreating value to an organization by creating strategic objectives that will lead to the growth of the company and would maintain a certain level of control over the company. Similar to that, here cloud organization is involved. There are several aspects of cloud governance out of which SLAs are one of the important aspects. SLAs are the set of rules that are defined between the user and cloud service provider that decide upon the QoS factor. IfSLAs are not followed, then the defaulter has to paythe penalty. The whole cloud is governed by keeping these SLAs in mind.Cloudgovernance is discussed in detail in further chapters.

MANAGING THE CLOUD APPLICATION

Business companies are increasingly looking to move or build their corporate applications on cloud platforms to improve agility or to meet dynamic requirements that exist in the globalization of businesses and responsiveness to market demands. But this shift or moving the applications to the cloud environment brings new complexities. Applications become more composite and complex, which requires leveraging not only capabilities like storage and database offered by the cloud providers but also third-party SaaS capabilities like e -mail and messaging. So, understanding the avail- ability of an application requires inspecting the infrastructure, the services it consumes, and the upkeep of the application. The composite nature of cloud applications requires visibility into all the services to determine the overall availabilityand uptime.

Cloud application management is to address these issues and propose solutions tomake it possible to have insight into the applicationthat runs inthe cloud, as wellas implement or enforce enterprise policies like governance and auditing and environment management while the application is deployed in the cloud. These cloud-based monitoring and management services can collect a multitude ofevents, analyze them, and identifycritical informationthat requires additionalremedial actions like adjusting capacity or provisioning new services. Additionally, application management has to be supported with tools and processes required for managing other environments that might coexist, enabling efficient operations.

MIGRATING APPLICATION TO CLOUD

Cloud migration encompasses moving one or more enterprise applications and theirITenvironments from the traditional hosting type to the cloud environment, either public, private, or hybrid. Cloud migration presents an opportunity to significantly reduce costs incurred on applications. This activity comprises, of different phases like evaluation, migration strategy, prototyping, provisioning, and testing.

PHASES OF CLOUD MIGRATION

Evaluation: Evaluation is carried out for all the components like current infrastructure and application architecture, environment in terms of compute, storage, monitoring, and management, SLAs, operational processes, financial considerations, risk, security, compliance, andlicensing needs are identified to build a business casefor moving to the cloud.

Migration strategy: Based on the evaluation, a migration strategy is drawn—a hot plug strategy is used where the applications and their data and interface dependencies are isolated and these applications can be operationalized allat once. A fusion strategy is used where the applications can be partially migrated; but for a portion of it, there are dependencies based on existing licenses, specialized server requirements like mainframes, or extensive interconnections with other applications.

Prototyping: Migration activity is preceded by a prototyping activity to validate and ensure that small portionofthe applications are testedonthe cloud environmentwithtestdatasetup.

Provisioning: Pre-migration optimizations identified are implemented. Cloud serversare provisioned for all the identified environments, necessary platform software and applications are deployed, configurationsaretunedto matchthe new environment sizing, and databasesand filesare replicated. All internal and external integration points are properly configured. Web services, batch jobs, and operation and management software areset up inthe new environments.

Testing: Post migration tests are conducted to ensure that migration has been successful. Performance and load testing, failure and recovery testing, and scale- out testing are conducted against the expected traffic load and resource utilization levels.

APPROACHES FOR CLOUD MIGRATION

The following are the four broad approaches for cloud migrationthat have beenadopted effectively byvendors:

1) ***Migrate existing applications***:Re build or re-architect some or all the applications,taking advantage ofsome ofthe virtualization technologies around to accelerate the work.

But,it requirestop engineersto developnew functionality.Thiscanbeachievedoverthecourseof severalreleases withthe timing determined bycustomerdemand.

2) ***Start from scratch*: ** Rather than cannibalize sales, confuse customers with choice, and tie up engineers trying to rebuild existing application, it may be easier to start again. Many of the R&D decisions will be different now, and with some of the more sophisticateddevelopment environments,one can achieve more evenwith a small focused working team.

3) ***Separate company*: ** One may want to create a whole new company with separate brand, management,R&D,andsales.Theinvestment and internet protocol(IP)may come from the existing company, but manyofthe conflicts disappear once a new *born in the cloud* company is established. The separate company may even be a subsidiary of the existing company. What is important is that thenew company can act, operate, and behavelike a cloud-based start-up.

4) ***Buy an existing cloud vendor*: ** For a large established vendor, buying a cloud-based competitorachievestwothings. Firstly, it removes acompetitor,and secondly, it enablesthevendor to hit the ground running in the cloud space. The risk of course is that the innovation, drive, and operational approach of the cloud- based company are destroyed as it is merged into the larger acquirer.

Cloud Deployment Models, Cloud Service Models, Technological Drivers for Cloud Computing: SOA and Cloud, Multicore Technology, Web 2.0 and Web 3.0, Pervasive Computing, Operating System, Application Environment

CLOUD SERVICE MODELS

Cloud Service Models: Infrastructure as a Service, Characteristics of IaaS. Suitability of IaaS, Pros and Cons of IaaS, Summary of IaaS Providers, Platform as a Service, Characteristics of PaaS, Suitability of PaaS, Pros and Cons of PaaS, Summary of PaaS Providers, Software as a Service, Characteristics of SaaS, Suitability of SaaS, Pros and Cons of SaaS, Summary of SaaS Providers, Other Cloud Service Models.

INTRODUCTION

Cloud computing is a model that enables the end users to access the shared pool of resources such ascomputer, network, storage, database, and application as an on- demand service without the need to buy or own it. The services are provided and managed by the service provider, reducing the management effort fromthe end user side.

The essential characteristics of the cloud include on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. The National Institute of Standards and Technology (NIST) define three basic service models, namely, IaaS, PaaS, and SaaS, as shown in Figure 4.1.

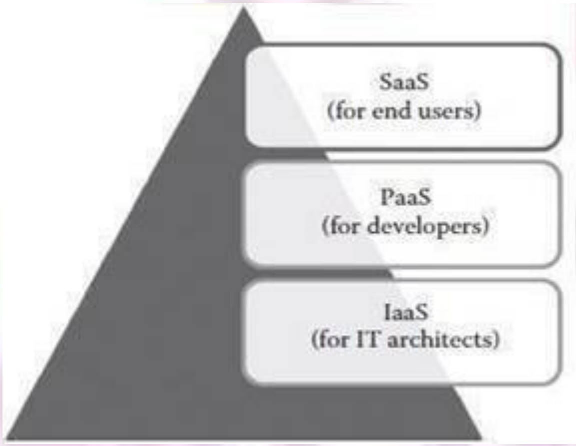


FIGURE4.1Basiccloudservicemodels.

The NIST definition of the three basic service models is given as follows:

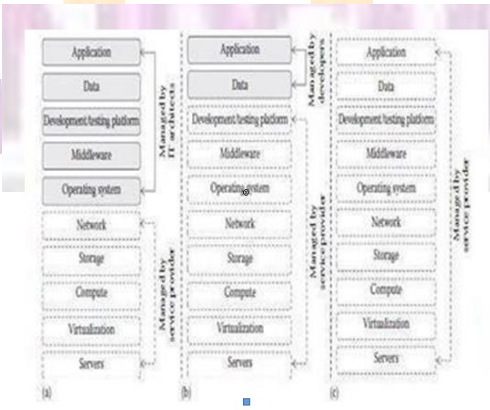
***IaaS*: The ability given to the infrastructure architects to deploy or run any software on the computingresources provided by the service provider.

Here, the underlying infrastructures such as computer, network, and storage are managed by the service provider. Thus, the infrastructure architects are exemptedfrom maintaining the data center or underlying infrastructure. The end users are responsible for managing applications that are running on top of the service provider cloud infrastructure. Generally, the IaaS services are pro- vided fromthe service provider cloud data center.

The end users can access the services fromtheir devices through web command line interface (CLI) or application programming interfaces (APIs) provided by the service providers. Some of the popular IaaS providers include Amazon Web Services (AWS), Google ComputeEngine, OpenStack, and Eucalyptus.

***PaaS*: **Theabilitygiventodeveloperstodevelopanddeployanapplicationonthedevelopment platformprovidedbytheserviceprovider.Thus, thedevelopersareexemptedfrommanaging the

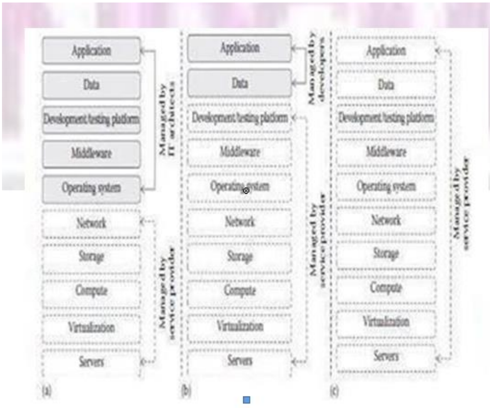
Development platform and underlying infrastructure. Here, the developers are responsible for managing the deployed application and configuring the developmentenvironment.
Generally, PaaS services are provided by the service provider on an on-premise or dedicated or hosted cloud infrastructure. The developers can access the development platform over the Internet through web CLI, web user interface (UI), and integrated development environments (IDEs). Some ofthe popular PaaS providers include Google App Engine, Force.com, Red Hat OpenShift, Heroku, and Engine Yard.



development platform and underlying infrastructure. Here, the developers are responsible for managing the deployed application and configuring the developmentenvironment.
Generally, PaaS services are provided by the service provider on an on-premise or dedicated or hosted cloud infrastructure. The developers can access the development platform over the Internet through web CLI, web user interface (UI), and integrated development environments (IDEs). Some ofthe popular PaaS providers include Google App Engine, Force.com, Red Hat OpenShift, Heroku, and Engine Yard.

***SaaS*:** The ability given to the end users to access an application over the Internet that is hosted and managedby the service provider.Thus, the end users are exempted from managing or controlling an application, the development platform, and the underlying infra-structure. Generally, SaaS services are hosted in service provider– managed or service provider–hosted cloud infrastructure. The end users can access the services from any thin clients or web browsers. Some of the popular SaaS providers include Saleforce.com, Google Apps, andMicrosoft office 365.
The different cloud service models target different audiences. For example, the IaaS model targets the information technology (IT) architects, PaaS targets the developers, and SaaS targets the end users. Based on the services subscribed, the responsibility of the targeted audience may vary as shown in Figure 4.2.
In IaaS, the end users are responsible for maintaining the development platformand the application running on top of the underlying infrastructure. The IaaS providers are responsible for maintaining the underlying hardware as shown in Figure 4.2.

In PaaS, the end users are responsible for managing the application that they have developed. The underlying infrastructure will be maintained bythe infrastructure provider as shown in Figure 4.2b. In SaaS, the end user is free from maintaining the infrastructure, development platform, and application that they are using. All the maintenance will be carried out by the SaaS providers as shown Figure 4.2c.



FGURE 4.2

User and serviceprovider responsibilitiesofcloud service models: (a) IaaS,(b) PaaS,and (c) SaaS. Thedifferentservice modelsofcloud computing can bedeployed and delivered throughanyone of the cloud deployment models. The NIST defines four different types ofcloud deployment models.

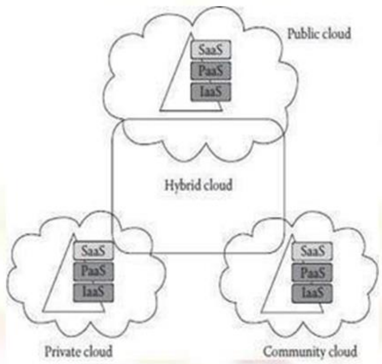


FIGURE 4.3 Deployment and delivery of different cloud service delivery models.

The hybrid cloud is any combination of the public,private,and community clouds.The service delivery of cloud services through different deployment models is shown in the figure.

This chapter discusses about the characteristics, suitability, and pros and cons of different cloud service models. Additionally, this chapter gives the summary of popular IaaS, PaaS, and SaaS providers.

INFRASTRUCTURE AS A SERVICE

IaaS changes the way that the compute, storage, and networking resources are consumed. In traditional data centers, the computing power is consumed by having physical access to the infrastructure. IaaS changes the computing from a physical infrastructure to a virtual infrastructure. IaaS provides virtual computing, storage, and network resources by abstracting the physical resources. Technology *virtualization* is used to provide the virtualresources.

All the virtual resources are given to the virtual machines (VMs) that are configured by the service provider. The end users or IT architects will use the infrastructure resources in the form of VMs as shown in Figure 4.4. maintained by the service providers. The physical infrastructure can be maintained by the service providers themselves. Thus, it eliminates or hides the complexity of maintaining the physical infrastructure from the IT architects. A typical IaaS provider may provide the flowing services as shown in Figure 4.5:

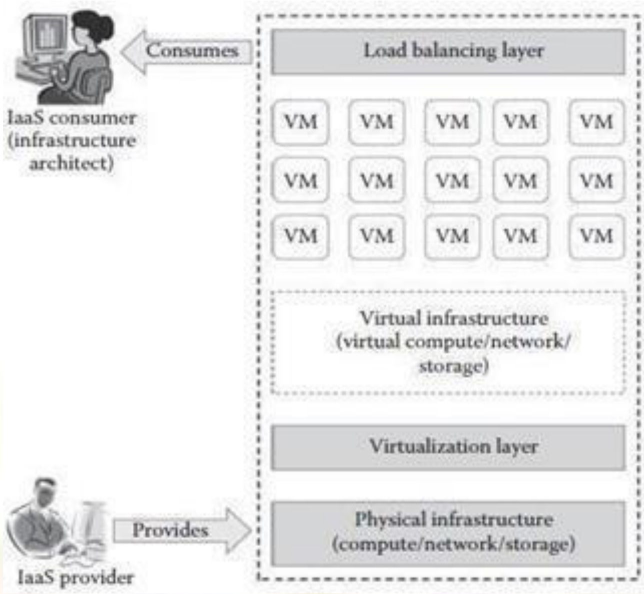


FIGURE4.4OverviewofIaaS.

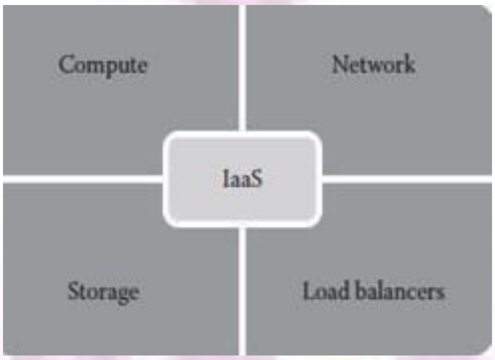


FIGURE4.5 ServicesprovidedbyIaaSproviders.

Compute: Computing as a Service includes virtual central processing units(CPUs) and virtual main memory for the VMs that are provisioned to the end users.
Storage:STaaS provides back-end storage for the VM images.Some of the IaaS providers also provide the back endfor storingfiles.
Network:Network as a Service(NaaS)provides virtual networking components such as virtual router, switch, and bridge for the VMs.
Load balancers: Load Balancing as a Service may provide load balancing capability at the infrastructure layer.

CHARACTERISTICS OF IAAS

IaaS providers offer virtual computing resources to the consumers on a pay-as- you- go basis. IaaS contains the characteristics of cloud computing such as on- demand self- service, broad network access, resource pooling, rapid elasticity, and measured service. Apart from all these, IaaS has its ownunique characteristics as follows:

***Web access to theresources*:** The IaaSmodelenables the IT usersto access infrastructureresources overthe Internet. Whenaccessing a huge computing power,the IT userneed not get physicalaccess to the servers.
Through any web browsers or management console, the users can access the required infrastructure.
***Centralized management*:** Even thoughthe physicalresources are distributed, the management will be from a single place. The resources distributed across different parts can be controlled from any management console. This ensures effective resource management and effectiveresourceutilization.
***Elasticity and dynamic scaling*:** IaaS provides elastic services where the usage of resources can be increased or decreased according to the requirements. The infrastructure need depends on the load on the application. According to the load, IaaS services can provide the resources. The load on any applicationisdynamicand IaaS servicesarecapableofproving therequired services dynamically.
***Shared infrastructure*:** IaaS follows a one-to-many delivery model and allows multiple IT users to share the same physical infrastructure.

The different IT users will be given different VMs. IaaS ensures high resource utilization.
***Preconfigured VMs*:** IaaS providers offer preconfigured VMs with operating systems (OSs), networkconfiguration, etc.The IT userscanselect anykindofVMsoftheir choice. TheIT users arefree to configure VMs fromscratch. The users can directly start using the VMs as soon as theysubscribed to the services.
***Metered services*:** IaaS allows the IT users to rent the computing resources insteadofbuying it. The services consumed by the IT user will be measured, and the users will be charged by the IaaS providers based onthe amount ofusage.

SUITABILITY OF IAAS

IaaS reduces the total cost of ownership (TCO) and increases the return on investment (ROI) for start-up companies that cannot investmore in buying infrastructure.
IaaS can be used in the following situations:
***Unpredictable spikes in usage*:** When there is a significant spike in usage of computing resources, IaaS is the best option for IT industries. Whendemand is very volatile, we cannot predict the spikes and troughs in terms of demand of the infrastructure. In this situation, we cannot add or remove infrastructure immediately according to the demand in a traditional infrastructure. If there is an unpredictable demand of infrastructure, then itis recommended to useIaaS services.
***Limited capital investment*:** New start-up companies cannot invest more on buying infrastructure for their business needs. And so byusing IaaS, start-up companies can reduce the capital investment on hardware. IaaS is the suitable option for start- up companies with less capital investment on hardware.
***Infrastructure on demand*:** Some organizations may require large infrastructure fora short period of time. For this purpose, an organization cannot afford to buy more on-premise resources. Instead, they can rent the required infrastructure for a specific period of time. IaaS best suitsthe organizations that look for infrastructure on demand or for a short time period. IaaS helps start-up companies limit its capital expenditure.While it is widelyused bystart-up companies.

In following situations, IT users should avoid using the IaaS:

When regulatory compliance does not allow off- premise hosting**:** For some companies, its regulation may not allow the application and data to be hosted on third-party off-premise infrastructure.

When usage is minimal**:** When the usage is minimal and the available on-premise infrastructure itself is capable ofsatisfying theirneeds.

When better performance is required**:** Since the IaaS services are accessed through the Internet, sometimes the performance might be not as expected dueto network latency.

When there is a need for more control on physical infrastructure**:** Some organizations might require physical control over the underlying- infrastructure. As the IaaS services are abstracted as virtual resources, it is not possible to have more control on under lying physical infrastructure.

PROS AND CONS OFIAAS

Being one of the important service models of cloud computing, IaaS pro-vides lot of benefits to the ITusers. The following are the benefits providedbyIaaS:

Pay-as-you-use model**:** The IaaS services are provided to the customers on a pay-per-use basis. Thisensures that the customers are required to pay for what they have used. This model eliminates the unnecessary spending on buying hardware. *Reduced TCO*: Since IaaS providers allow the IT users to rent the computing resources, they need not buy physical hardware for running their business. The IT user scan rent theIT infrastructure rather than buy it by spending large amount.
IaaS reduces the need for buying hardware resources and thus reduces theTCO.

Elastic resources**:** IaaS provides resources based on the current needs. IT users can scale up or scale down the resources whenever they want. This dynamic scaling is done automatically using some load balancers. This load balancer transfers the additional resource request to the new server and improves application efficiency. *Better resource utilization*: Resource utilization is the most important criteria to succeed in the IT business. The purchased infrastructure should be utilized properly to increase the ROI. IaaS ensures better resource utilization and provideshigh ROIfor IaaS providers.

Supports Green IT**:**In traditional IT infrastructure, dedicated serversare used for different business needs. Since many servers are used, the power consumption will be high. This does not result in Green IT. In IaaS, the need of buying dedicated servers is eliminated as single infrastructure is shared between multiple customers, thus reducing the number of servers to be purchased and hence the power consumption thatresults in Green IT.
Even though IaaS provides cost-related benefits to small- scale industries, it lacks in providing security to the data. The following are the drawbacks of IaaS: *Security issues*: Since IaaS uses virtualization as the enabling technology, hypervisors play an important role.There are manyattacks that target the hypervisors to compromise it. If hypervisors get compromised, then anyVMs canbe attacked easily. Most of the IaaS providers are not able to provide 100% securityto the VMs and the data stored onthe VMs.

Interoperability issues**:** There are no common standards followed among the different IaaS providers. It is very difficultto migrate any VM from one IaaSprovider to the other. Sometimes, the customers mightface the vendor lock- inproblem.

Performance issues**:** IaaS is nothing but the consolidation of available resources fromthe distributed cloud servers. Here, allthe distributed servers are connected over the network.

Latency of the network plays an important role in deciding the performance. Because of latency issues, sometimes theVM contains issues with its performance.

Public IaaS consumers need not consider the host OS as it is maintained bythe service provider. In managing the private cloud, the users should see the supported host OS. However, most of the private IaaS supports popular guest OS, fully dependingon the hypervisor that the IaaS providers aresupporting.

PLATFORM AS A SERVICE

PaaS changes the waythat the software is developed and deployed. Intraditional application development,the application will be developed locally and will be hosted inthe central location. In stand-alone application development, the applications will be developed and delivered as executables. Most of the applications developed by traditional development platforms result in Licensing based software, whereas PaaS changes the application development from local machine toonline. PaaS providers provide the development PaaS from the data center. The developers can consume the services over the Internet as shown in Figure 4.6.

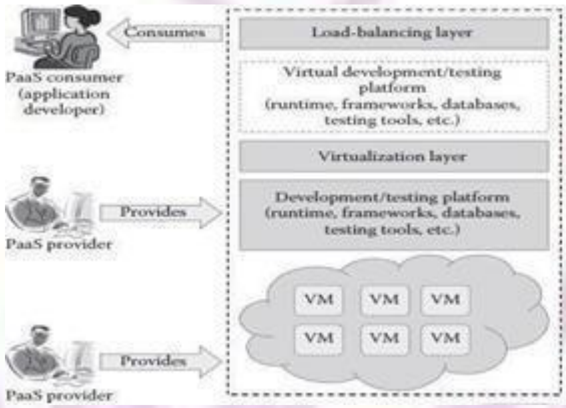


FIGURE4.6 Overview of PaaS.

PaaS allows the developers to develop their application online and also allows them to deploy immediately on the same platform.

PaaS consumers or developers can consume language runtimes, application -frameworks, databases, message queues, testing tools, and deployment tools as aser- vice over the Internet. Thus, it reduces the complexity of buying and - maintaining different tools for developing an application. Typical PaaS providers may provide programming languages, application frameworks, databases, and testing tools as shown in Figure 5.7. Some of the PaaS providers also provide build tools, deploymenttools, and software load balancers as a service:

Programminglanguages**:** PaaS providers provide a wide varietyofprogramming languages forthe developers to develop applications. Some ofthe popular programming languages provided byPaaS vendors are Java, Perl, PHP, Python, Ruby, Scala, Clojure, and Go.

Application frameworks**:** PaaS vendors provide application frame-works that simplify the applicationdevelopment.Someofthepopularapplicationdevelopment frameworksprovided bya PaaS provider include Node.js, Rails, Drupal, Joomla, WordPress, Django, EE6, Spring, Play, Sinatra, Rack, and Zend. *Database*: Since everyapplication needs to communicate with the databases,it be comes a must-have tool for every application.PaaS providers are providing databases also with their PaaS plat-forms.

The popular databases provided by the popular PaaS vendors are ClearDB,PostgreSQL,Cloudant, Membase,

MongoDB, and Redis.
***Othertools*:**PaaSprovidersprovideallthetoolsthatarerequiredto develop,test,anddeployan application.

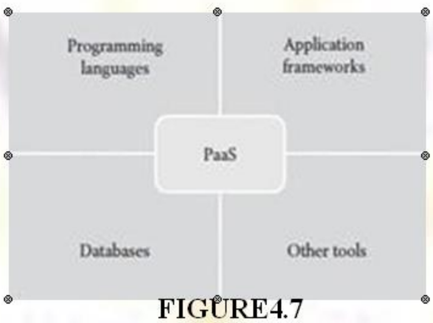


FIGURE4.7
Services provided by PaaS providers.

CHARACTERISTICS OF PAAS

PaaS development platforms are different from the traditional application development platforms. The following are the essential characteristics that make PaaS unique fromtraditional development platforms:

***All in one*:** Most of the PaaS providers offer services to develop, test, deploy, host, and maintain applications in the same IDE. Additionally, many service providers provide all the programming languages, frameworks, databases, and other development-related services that make developers choose froma wide varietyofdevelopmentplatforms.

***Web access to the development platform*:** A typical development plat-form uses any IDEs for developing applications. Typically, the IDE will be installed inthe developer's machines. But, PaaS provides web access to the development platform. Using web UI, any developer can get access to thedevelopment platform. The web- based UI helps the developers create, modify, test, and deploy differentapplications onthe same platform.

***Offline access*:** Adeveloper may not be able to connect tothe Internet for a whole dayto access the PaaS services. When there is no Internet connectivity, the developers should be allowed to work offline. To enable offline development, some of the PaaS providers allow the developer to synchronize their local IDE with the PaaS services. The developers can develop an application locallyand deploy itonline whenevertheyare connected to the Internet.

***Built-in scalability*:** Scalability is an important requirement for the new-generation web or SaaS applications. It is very difficult to enable the dynamic scalability forany application developedusing traditional development platforms. But, PaaS services provide built-in scalability to an application that is developed using any particular PaaS. This ensures that the application is capable of handling varying loads efficiently.

***Collaborative platform*:** Nowadays, the development team consists of developers who are working from different places. There is a need for a common platform where the developers can collaboratively work together onthe same project.

Most of the PaaS services pro-vide support collaborative development. To enable collaboration among developers,most of the PaaS providers provide tools for project planning.

***Diverse client tools*:** To make the development easier, PaaS providers provide a wide variety of client tools to help the developer. The client tools include CLI, web CLI, web UI, REST API, and IDE. The developers can choose any tools of their choice. These client tools are also capable of handling billing and subscription management.

SUITABILITY OFPAAS

Most of the start-up SaaS development companies and independent software vendors(ISVs)widely use PaaS in developing an application. PaaS technology is getting attention from other traditional software development companies also. PaaS is a suitable option for the following situations:

***Collaborative development*:**To increasethetime tomarket and development efficiency, thereisa need foracommonplacewherethedevelopment teamandotherstakeholdersoftheapplicationcan collaboratewitheachother. Since PaaS servicesprovide acollaborative developmentenvironment, it is a suitable option for applications that need collaboration among developers and other third parties to carryout the developmentprocess.

***Automated testing and deployment*:** Automated testing and building of an application are very usefulwhile developing applications at a very short time frame. The automated testing tools reduce the time spent in manual testing tools. Most of the PaaS services offer automated testing and deployment capabilities. The development team needs to concentrate more on development rather than testing and deployment. Thus, PaaS services are the best option where there is a need for automated testing and deploymentofthe applications.

***Timetomarket*:**The PaaS services follow the iterativeand incremental development methodologies that ensure that the application is in the market as per the time frame given. For example, the PaaS services arethebest optionfor applicationdevelopment that usesagiledevelopment methodologies. Ifthe software vendor wants their application to be in the market as soon as possible, then the PaaS services are the best option for the development.

PaaS is used widelyto accelerate the application development process to ensure the time to market. Most of the start-up companies and ISVs started migrating to the PaaS services. Even though it is used widely, there aresome situations wherePaaS maynot bethe bestoption:

***Frequent application migration*:** The major problem with PaaS services are vendor lock-in. Since there are no common standards followed among PaaS providers, it is very difficult to migrate the application fromone PaaS provider to the other.

***Customization at the infrastructure level*:** PaaS is an abstracted service, and the PaaS users do not have full control over the underlying infrastructure. There are some application development platforms that need some configurationor customizationofunderlyinginfrastructure.

In these situations, it is not possible to customize the underlying infrastructure with PaaS. If the application development platform needs any configuration at the hardware level, it is not recommended to go for PaaS.

***Flexibility at the platform level*:** PaaS provides template- based applications where allthe different programming languages, databases, and message queues are predefined. It is an advantage if the application is a generic application.

***Integration with on-premise application*:** A company might have used PaaS servicesfor some set ofapplications. For some set ofapplications, theymight have used on- premise platforms.

Since many PaaS services use their own proprietary technologies to define the application stack, it may not match with the on-premise application stack. This makes the integration of application hosted in on-premise plat-formand PaaSplatforma difficultjob.

PROS AND CONS OF PAAS

The main advantage of using PaaS is that it hides the complexity of maintaining the platform and underlying infrastructure. This allows the developers to work more on implementing the important functionalities ofthe application. Apart fromthis, the PaaS hasthe followingbenefits:

Quick development and deployment**:** PaaS provides all the required development and testing tools todevelop,test, anddeploythesoft-wareinoneplace. MostofthePaaSservicesautomatethe testing and deployment process as soon as the developer completes the development. This speeds up applicationdevelopmentanddeployment thantraditionaldevelopmentplatforms.

ReducesTCO**:** Thedevelopers need not buylicenseddevelopment andtestingtools ifPaaSservices are selected. Most of the traditional development platforms requires high- end infrastructure for its working, which increases the TCO of the application development company. But, PaaS allows the developers to rent the software, development platforms, and testing tools to develop, build, and deploy the application. PaaS does not require high-end infrastructure also todevelopthe application, thus reducing the TCOofthe developmentcompany.

Supports agile software development**:** Now a days, most of the new-generation applications are developed using agile methodologies. Many ISVs and SaaS development companies started adopting agile methodologies for application development. PaaS services support agile methodologies that the ISVs and other developmentcompanies are lookingfor.

Different teams can work together**:** The traditionaldevelopment plat-formdoes not have extensive supportfor collaborative development.

PaaS services support developers from different places to work together on the samep roject. This is possible becauseoftheonline commondevelopmentplatformprovidedbyPaaSproviders.

Ease of use**:** The traditional development platform uses any one of CLI- or IDE- basedinterfaces for development. Some developers may not be familiar with the interfaces provided by the application development platform. This makes the development job a little bit difficult. But, PaaS provides a wide variety of client tools such as CLI, web CLI, web UI, APIs, and IDEs. The developers are free to choose any client tools of their choice. Especially, the web UI–based PaaS services increasethe usabilityofthe developmentplatformfor alltypes ofdevelopers.

Less maintenance overhead**:** In on-premise applications, the development company or software vendor is responsible for maintaining the underlying hardware. They need to recruit skilled administrators to maintain the servers. This overhead is eliminated by the PaaS services as the underlying infrastructure is maintained by the infra-structure providers. This gives freedom to developers to work on the application development.

Produces scalable applications: Most of the applications developed using PaaS services are web application or SaaS application. These applications require better scalability on the extra load. For handling extra load, the software vendors need tomaintain an additional server. Itis very difficult for anew start-up companyto provide extra servers based onthe additional load.

But, PaaS services are providingbuilt-in scalabilityto the application thatis developedusingthe PaaS platform.

PaaS provide sa lot ofbenefitsto developerswhencompared to the traditional development environment. Ontheother hand, it contains drawbacks, which aredescribed in the following:

Vendor lock-in**:** The major drawback with PaaS providers are vendor lock-in. The main reason forvendor lock-in is lack of standards. There are no common standards followed among the differentPaaS providers. The other reason for vendor lock-in is proprietary technologies used by

PaaSproviders. Most of the PaaS vendors use the proprietary technologies that are not compatible withthe otherPaaS providers.The vendorlock-in problem of PaaS services does not allow theapplications to be migrated fromone PaaS provider to the other.

Security issues: Like in the other cloud services, security is one of the majorissuesin PaaS services. Since data are stored in off--premise third-party servers, many developers are afraid to go for PaaS services. Ofcourse, manyPaaS providers provide mechanismsto protect the userdata,and itis not sufficient to feel the safety of on-premise deployment. When selecting the PaaS provider, the developer should review the regulatory, compliance, and security policies of the PaaS provider with their own security requirements. If not properly reviewed, the developers or users areat the risk of data security breach.

Less flexibility: PaaS providers do not give much freedom for the developers to define their own applicationstack. Most of the PaaS providers provide many programming languages, databases, and other development tools. But, it is not extensive and does not satisfyalldeveloperneeds.

Only some ofthe PaaS providers allow developers-to extend the PaaS tools with the customor new programming languages. Still most of the PaaS providers do not provide flexibility tothe developers.

Depends on Internet connection: Since the PaaS services are delivered over the Internet, the developers should depend on Internetconnectivity for developing the application. Even though some of the providers allow offline access, most of the PaaS providers do not allow offline access. With slow Internet connection, the usability and efficiency of the PaaS platform do not satisfy the developer requirements.

SOFTWARE AS A SERVICE

Business services: Most of the SaaS providers started providing a variety of business services that attract start-up companies. The business SaaS services include ERP, CRM, billing, sales, and humanresources.

Social networks: Since social networking sites are extensively used by the general public, many social networking service providers adopted SaaSfor their sustainability. Since the number ofusers of the social networking sites is increasing exponentially, cloud computing is the perfect match for handling the variable load. *Document management*: Since most of the enterprises extensively use electronic documents, most ofthe SaaS providers started providing services that are used to create, manage, and track electronic documents.

Mail services: E-mail services are currently used by many people. The future growth in e-mail usage is unpredictable. To handle the unpredictable number of users and the load one-mail services, most ofthe e- mail providers started offering their services as SaaS services.

CHARACTERISTICS OF SAAS

SaaS services are different and give more benefits to end users than the traditional software. The following are the essential characteristics of SaaS ser-vices that make it unique from traditional software:

One to many: SaaS services are delivered as a one-to- many model where a single instance of the application can be sharedby multiple tenants or customers.

Web access: SaaS services provide web access to the software. It allows the end user to access the application fromany location if the device is connectedto the Internet.

Centralized management: Since SaaS services are hosted and man-aged from the central location, management ofthe SaaS applicationbecomes easier. Normally, the SaaS providers willperformthe automatic updates that ensure that each tenant is accessing the most recent version of the applicationwithout anyuser-side updates.

Multidevice support: SaaS services can be accessed from any end user devices such as desktops, laptops, tablets, smartphones, and thin clients.

Better scalability: Since most of the SaaS services leverage PaaS and IaaS for its development and deployment, it ensures a better scalability than the traditional software. The dynamic scaling of underlying cloud resources makes SaaS applications work efficiently even with varyingloads.

High availability: SaaS services ensure the 99.99% availability of user data as proper backup and recovery mechanisms areimplemented at the back end.

API integration: SaaS services have the capability of integrating with other software or service through standard APIs.

SUITABILITY OF SAAS

SaaS is popular among individuals and start-upcompanies because ofthe benefits it provides. Most of the traditional software users are looking for SaaS versions of the software as SaaS has several advantagesover traditionalapplications. SaaS applications arethe best option forthe following:

On-demand software: The licensing-based software model requires buying full packaged software and increases the spending on buying software. Some of the occasionally used software does not give any ROI. Because of this, many end users are looking for a software that they can use as and when they needed. If the end users are looking for on-demand software rather than the licensing- based full-termsoftware, thenthe SaaSmodelis the bestoption.

Software for start-up companies: When using any traditional software, the end user should buy devices with minimum requirements specified by the software vendor. This increases the investment on buying hardware for start- up companies. Since SaaS services do not requirehigh- end infrastructure for accessing, it is a suitable option for start- up companies that can reduce the initial expenditure on buying high-end hardware.

Software compatible with multiple devices: Some of the applications like word processors or mail services need better accessibilityfromdifferent- devices. The SaaS applications are adaptable with almost all the devices.

Software with varying loads: We cannot predict the load on popular applications such as social networking sites. The user may connect or disconnect fromapplications anytime. It is verydifficult to handle varying loads with the traditional infrastructure. With the dynamic scaling capabilities, SaaS applications can handle varying loads efficientlywithout disrupting the normalbehaviorofthe application. Most of the traditional software vendors moved to SaaS business as it is an emerging software delivery model that attracts end users. But still many traditional applications donot have its SaaS versions. This implies that SaaS applications may not be the best option for all types of software. The SaaS delivery model is not the best option for the applications mentioned in the following:

Real-time applications: Since SaaS applications depend on Internet connectivity, it may not work better with low Internet speed. If data are stored far away from theend user, the latency issues may delay the data retrieval timings. Real- time applications require fast processing of data that may not be possible with the SaaS applications because of the dependency on high-speed Internet connectivity andlatency issues.

Applications with confidential data: Data security, data governance, and datacompliance are always issues with SaaS applications. Since data arestored withthird- party serviceproviders, thereis no suretythatourdatawillbe safe.Ifthe storedconfidentialdatagetlost,It will make aseriouslosstothe organization. It is not recommendedtogofor SaaS for applications that handleconfidential data.

Better on-premise application: Some of the on-premise applications might fulfill all the requirements of the organization. In such situations, migrating to the SaaS model may not be the best option.

PROSAND CONS OF SAAS

SaaS applications are used bya wide range of individuals and start-up industries for its cost-related benefits. Apart fromthecost-relatedbenefits, SaaSservicesprovidethe followingbenefits:

No client-side installation: SaaS services do not require client-side installation ofthe software. The end users can access the services directly from the service provider data center without any installation.Thereisno needofhigh- end hardwareto consume SaaS services.

It can be accessed from thin clients or any handheld devices, thus reducing the initial expenditure on buying high-end hardware.

Cost savings: Since SaaS services follow the utility-based billing or pay-as-you- go billing, it demands the end users to pay for what they have used. Most of the SaaS providers offer different subscription plans to benefit different customers.Sometimes, the generic SaaS services such as word processors are given forfree to the end users.

Less maintenance: SaaS services eliminate the additional overhead of maintaining the software from the client side. For example, in the traditional software, the end user is responsible for performing bulk updates. But in SaaS, the service provider itself maintains the automatic updates, monitoring, and other maintenance activities ofthe applications.

Ease of access: SaaS services can be accessed from any devices if it is connected to the Internet. Accessibility of SaaS services is not restricted to any particular devices. It is adaptable to all the devices as it uses the responsive web UI. *Dynamic scaling*: SaaS services are popularly known for elastic dynamic scaling. It is very difficult for on-premise software to pro-vide dynamic scaling capability as it requires additional hardware. Since the SaaS services leverage elastic resources provided bycloud computing, it canhandle anytype ofvarying loads without disrupting the normal behavior ofthe application.

Disaster recovery: Withproper backup and recoverymechanisms, replicasare maintained for every SaaS services. The replicas are distributed across many servers. If any server fails, the end user can accesstheSaaS fromotherservers.Iteliminatestheproblemofsinglepoint offailure. It also ensures the highavailability ofthe application.

Multitenancy: Multitenancy is the ability given to the end users to share a single instance of the application. Multitenancy increases resource utilization fromthe service providerside.

The following are the major problems with SaaS services:

Security: Security is the major concern in migrating to SaaS application. Since the SaaS applicationis shared between manyend users, there is a possibilityofdata leakage.

Here, the data are stored in the service provider data center. We cannot simply trust some third-partyservice provider to store our company-sensitive and confidential data. The end user should be carefulwhile selecting the SaaS provider to avoid unnecessarydata loss.

Connectivity requirements: SaaS applications require Internet connectivity for accessing it. Sometimes, the end user's Internet connectivity might be very slow. In such situations, the user cannot access the services with ease.

Summary of Popular SaaS Providers

Provider	Services Provided
Salseforce.com	On-demand CRM solutions
Google Apps	Gmail, Google Calendar, Talk, Docs, and Sites
Microsoft Office 356	Online office suite, software, plus services
NetSuite	ERP, accounting, order management, inventory, CRM, professional services automation (PSA), and e-commerce applications
Concur	Integrated travel and expense management solutions
GoToMeeting	Online meeting, desktop sharing, and video-conferencing software
Constant Contact	E-mail marketing, social-media marketing, online survey, event marketing, digital storefronts, and local deals tools
Workday, Inc.	Human capital management, payroll, and financial management
Oracle CRM	CRM applications
Intacct	Financial management and accounting software solutions

Table4.3

Table4.3

The dependency on high-speed Internet connection is a major problem in SaaS applications.

Loss of control: Since the data are stored in a third-party and off-premise location,theend user does not have any controlover the data. The degree ofcontrolover the SaaS application and data is lesser than the on-premise application.

SUMMARY OF SAAS PROVIDERS

There are many SaaS providers who provide SaaS services such as ERP, CRM, billing, document management, and mailservices. Table 4.3 givesa summaryofpopular SaaS vendors inthe market.

OTHER CLOUD SERVICE MODELS

ThebasiccloudservicessuchasIaaS, PaaS, andSaaSarewidelyused bymanyindividualand start- up companies. Now, cloud computing becomes the dominant technology that drives the IT world. Because of the extensive use of basic cloud services, the end users realize the importance and benefits ofspecific services suchas network, storage, and database. The basic cloud service models arethe unified models that contain multiple services in it. Now, the end users' expectationchanged, and theyare expecting the individualservices to beoffered byservice providers.

This makes most of the service providers to think about the separate services that meet end user requirements. Many service providers already started offering separate ser-vices such as network, desktop, database, and storageondemand as given inthefollowing:

NaaS is an ability given to the end users to access virtual network services that are provided by the service provider. Like other cloud service models, NaaS is also a business model for delivering virtual network services over the Internet ona pay-per-use basis.

In on-premise data center, the IT industries spent a lot of money to buy networkhardware to manage in-house networks. But, cloud computing changes networking services into a utility-based service. NaaS allows network architects to create virtual networks, virtual network- interface cards (NICs), virtualrouters, virtualswitches, and other networking components.

Additionally, it allows the network architect to deploy custom routing protocols and enables the designof efficient in-network services, such as data aggregation, stream processing, and caching. Some of the popular services provided by NaaS include virtual private network (VPN), bandwidth on demand (BoD), and mobile network virtualization.

Desktop as a Service (*DEaaS*) is an ability given to the end users to use desktop virtualization without buying and managing their own infrastructure. DEaaS is a pay-per-use cloud service delivery model in which the service provider manages the back-end responsibilities of data storage, backup, security, and upgrades. The end users are responsible for managing their own desktop images, applications, and security.

Accessing the virtual desktop provided by the DEaaS provider is device, location, and network independent. DEaaSser-vices are simpletodeploy, arehighlysecure, andproducebetterexperience on almostall devices.

STaaS is an ability given to the end users to store the data on the storage services provided by the service provider. STaaS allows the end users to access the files at any time from any place. The STaaS provider provides the virtual storagethat is abstracted fromthe physicalstorageofanycloud data center. STaaS is also a cloud business model that is delivered as a utility. Here, the customers can rent the storage from the STaaS provider. STaaS is commonly used as a backup storage for efficientdisaster recovery.

BaaS is an abilitygiven to the end users to access the database ser-vice without the need to install and maintain it. The service provider is responsible for installing and maintaining the databases.

The end users can directly access the services and can pay according to their usage. DBaaS automates the database administration process. The end users can access the database services through any API or web UIs provided by the service provider. The DBaaS eases the database administration process. Popular examples ofDBaaS include SimpleDB, DynamoDB, MongoDB asa Service, GAE datas- tore, and ScaleDB.

Data as a Service (*DaaS*) is an abilitygiven to the end users to access the data that are provided by the service provider over the Internet. DaaS provides data on demand. The data may include text, images, sounds, and videos. DaaS is closely related to other cloud service models such as SaaS and STaaS.

DaaS can be easily integrated with SaaS or STaaS for providing the composite service. DaaS is highlyused in geographydata services and financialdata services. The advantages ofDaaS include agility, cost effectiveness, and data quality.

SECaaS is an ability given to the end user to access the security service provided by the service provider on a pay- per-use basis.In SECaaS, the service providerintegrates theirsecurity services to benefit the end users. Generally, the SECaaS includes authentication, antivirus, antimalware/spyware, intrusion detection, and security event management. The security services provided by the SECaaS providers are typically used for securing the on-premise or in-house infrastructure and applications. Some of the SECaaS providers include Cisco, McAfee, Panda Software, Symantec, Trend Micro, and VeriSign.

IDaaS is an abilitygiven to the end users to access the authentication infrastructurethat is managed and provided bythe third-partyservice provider. The end user of IDaaS is typically an organization or enterprise. Using IDaaS services, any organization can easily manage their employees' identity without any additional overhead. Generally, IDaaS includes directory services, federated services, registration, authentication services, risk and event monitoring, single sign-on services, and identity and profile management.

The different new service models discussed in this section emerged after the introduction of cloud computing. This field still evolves and introduces new servicemodels based on the end user's needs. Many researchers from industry and academia already started introducing their innovative idea to take cloud computing to the next level. Apart from the service models discussed in this chapter, cloud computing researchers are thinking to add more service models.

Now,cloudcomputing movestothescenariowhereeverythingcanbegivenasaservice.

This can be termed as Everything as a Service (XaaS). In the future, we expect many new service models to achieve the goal of XaaS. XaaS may include Backup as a Service(BaaS),Communication as a Service(CaaS), Hadoop as a Service (HaaS), Disaster Recovery as a Service (DRaaS), Testing as a Service (TaaS), Firewall as a Service (FWaaS), Virtual Private Network as a Service (VPNaaS), Load Balancers as a Service (LBaaS), Message Queue as a Service (MQaaS), and Monitoring as a Service(MaaS).

UNIT III

Virtualization, Programming Models for Cloud Computing: Map Reduce, Cloud Haskell, Software Development in Cloud

INTRODUCTION

Virtualization is the process of creating a virtual (rather than physical) version of something, such as an operating system, server, storage device, or network resource.

Types of Virtualization:

1. **Hardware Virtualization:**

   Hypervisor creates multiple virtual machines (VMs) on a single physical machine.

   Types of hypervisors:

   Type 1 (Bare-metal): Runs directly on hardware (e.g., VMware ESXi, Microsoft Hyper-V).

   Type 2 (Hosted): Runs on top of an OS (e.g., Oracle VirtualBox).

2. **Operating System Virtualization:**

   Allows multiple isolated user-space instances (containers) on a single OS kernel.

   Example: Docker, LXC.

3. **Storage Virtualization:**

   Combines multiple physical storage resources into a single storage device.

4. **Network Virtualization:**

   Combines hardware and software network resources into a single virtual network.

5. **Application Virtualization:**

   Allows applications to run in environments that are different from the native OS.

Benefits of Virtualization:

- Better resource utilization
- Scalability and flexibility
- Cost reduction
- Easy backup and disaster recovery
- Isolation and security between virtual environments

Programming Models for Cloud Computing

These models help developers write applications that can run efficiently in cloud environments.

A. MapReduce Programming Model

Concept:

- A programming model for processing and generating large data sets with a parallel, distributed algorithm.

Phases:

1. **Map Phase:**
    - Input data is split and processed in parallel.
    - Output: Key-value pairs.
2. **Shuffle Phase:**
    - Group's key-value pairs by key.
3. **Reduce Phase:**
    - Aggregates or processes grouped data to generate the final result.

Example:

Word count from large documents.
Map: Emit (word, 1)
Reduce: Sum up counts per word.

Tools:

- Hadoop, Apache Spark.

B. Cloud Haskell

Definition:

- A distributed programming model based on the Haskell language.
- Allows writing cloud-ready parallel and distributed programs with strong type safety.

Features:

- Pure functional approach
- Lightweight process creation
- Message-passing communication
- Fault tolerance with supervision trees

C. Other Models

1. **Dataflow Programming:**
    - Represents computation as directed graphs of data flowing between operations (e.g., TensorFlow).
2. **Actor Model:**
    - Concurrency model where actors are the fundamental units of computation (used in Akka).
3. **Serverless Computing Model (Function as a Service – FaaS):**

- Write individual functions triggered by events (e.g., AWS Lambda, Azure Functions).
- No need to manage servers.

4. **Workflow Models:**
   - Series of tasks with dependencies represented as directed acyclic graphs (DAGs), e.g., Apache Airflow.

Diagram: Virtualization and Programming Model Overview

```
pgsql
CopyEdit
                +-----------------------------+
                |     Cloud Infrastructure    |
                +-----------------------------+
                         |       |
         +---------------+       +-----------------+
         |                                         |
+-----------------+                      +-------------------+
| Virtualization |                      | Programming Model |
+-----------------+                      +-------------------+
| - VM, Docker    |                      | - MapReduce        |
| - Hypervisor    |                      | - Cloud Haskell    |
| - OS-level      |                      | - FaaS, Actor      |
+-----------------+                      +-------------------+
```

MapReduce

➤ Definition:

MapReduce is a **programming model** for processing **large datasets** using a **distributed algorithm** on a cluster.

Steps:

Phase	Description	Output Example
Map	Takes input and produces key-value pairs	(“cat”, 1), (“dog”, 1)
Shuffle	Groups values by key	(“cat”, [1, 1]), (“dog”, [1])
Reduce	Combines values per key	(“cat”, 2), (“dog”, 1)

Use Case: **Word counting, log analysis, sorting, indexing large data.**
Frameworks: **Hadoop, Spark (optimizes MapReduce), Google Cloud Dataflow.**

---

2. Cloud Haskell

Definition:

Cloud Haskell is a **distributed programming framework** based on the **Haskell language**, designed for **cloud computing and concurrency**.

Key Features:

- Pure functional programming
- Type safety and immutability
- Actor-like lightweight processes
- Message-passing between processes (like Erlang)
- Fault tolerance using supervision models

Advantages:

- Strong compile-time checks

- Better support for concurrent & distributed systems
- High-level abstraction for scalable apps

Use Cases: Distributed computing, real-time systems, cloud-native applications

3. Software Development in Cloud

Definition:

This refers to the development, testing, and deployment of software **on cloud platforms** using **cloud-based tools and services**.

Phases of Cloud Software Development:

Phase	Cloud Tools Used
Coding	GitHub, GitLab, AWS Cloud9, Replit
Build & Test	Jenkins, Travis CI, Azure Pipelines
Deploy	AWS Elastic Beanstalk, Heroku, Netlify
Monitor	Prometheus, New Relic, Grafana

Benefits:

- Access from anywhere
- Collaboration in real time
- Scalable infrastructure
- Pay-as-you-go pricing
- Continuous Integration/Delivery (CI/CD)

Example:

A developer writes code in **AWS Cloud9**, pushes it to **GitHub**, triggers CI/CD pipeline in **Jenkins**, and deploys to **AWS Lambda**.

Summary Table:

Topic	Core Idea	Tools/Tech Examples
MapReduce	Process large data in parallel	Hadoop, Spark
Cloud Haskell	Distributed Haskell programming	GHC, distributed-process
Software in Cloud	Build, test, deploy in cloud	GitHub, AWS, Jenkins

UNIT IV

Networking for Cloud Computing: Introduction, Overview of Data Center Environment, Networking Issues in Data Centers, Transport Layer Issues in DCNs, Cloud Service Providers

Networking for Cloud Computing

Definition:

Networking for cloud computing refers to the **set of technologies and protocols** that enable **data transfer**, **resource sharing**, and **communication** between devices and services in a **cloud environment**.

Cloud computing heavily depends on **robust and secure networking** to ensure seamless access to resources like **storage**, **compute**, **applications**, and **databases** over the **Internet or private networks**.

Key Concepts in Cloud Networking

1. Virtual Private Cloud (VPC)

- A **logically isolated section** of a public cloud (e.g., AWS, Azure).
- Allows users to define **IP address ranges**, **subnets**, **routing tables**, and **gateways**.

2. Subnets

- Divide a large IP network into **smaller segments**.
- Used for organizing and securing resources in a VPC.

3. Internet Gateway

- Connects a VPC to the public Internet.
- Used when cloud resources (like web servers) need to be publicly accessible.

4. NAT Gateway (Network Address Translation)

- Allows instances in a **private subnet** to access the Internet **without being exposed** to incoming traffic.

5. Load Balancers

- Distribute incoming traffic across multiple servers.
- Improves **availability** and **performance**.

Cloud Networking Models

Model	Description	Example Use
Public Cloud	Network resources shared among many users	AWS, Azure
Private Cloud	Dedicated network environment for a single organization	VMware vCloud
Hybrid Cloud	Mix of public and private networks	Data backup between cloud and on-prem
Multi-Cloud	Use of multiple cloud service providers	AWS + GCP + Azure

Networking Protocols in Cloud

Protocol	Purpose
HTTP/HTTPS	Web communication
TCP/IP	Core internet protocol stack
DNS	Resolves domain names
VPN	Secure remote access
BGP	Routing between data centers

Technologies Used

Tech	Functionality
SDN (Software Defined Networking)	Programmable, dynamic network control
NFV (Network Function Virtualization)	Virtualize routers, firewalls, load balancers
Content Delivery Networks (CDNs)	Speed up content delivery globally
Firewalls/Security Groups	Control traffic flow & access control

---

Importance of Networking in Cloud Computing

- **High Availability:** Redundancy and routing prevent downtime.
- **Scalability:** Quickly expand services globally.
- **Security:** Protect resources with isolation and encryption.
- **Performance:** Optimized routing ensures fast access to services.

Example: AWS Cloud Networking Setup

- **VPC** with 2 subnets: Public (web server) and Private (database).
- **Internet Gateway** connected to the public subnet.
- **NAT Gateway** for private subnet to access updates.
- **Security Groups** to control access.
- **Elastic Load Balancer** for distributing traffic.

Overview of Data Center Environment

Definition:

A **Data Center** is a **facility** used to house **computing resources** such as **servers**, **storage systems**, **network devices**, and **software**, essential for **storing, processing, and managing data**.

In **cloud computing**, data centers form the **physical foundation** where cloud services (like AWS, Azure, Google Cloud) run.

Core Components of a Data Center

Component	Description
Compute (Servers)	High-performance machines that run applications and services.
Storage Systems	Devices like SSDs, HDDs, SAN, NAS used to store data.
Network Devices	Routers, switches, firewalls to connect and protect systems.
Power & Cooling	UPS, generators, air conditioning for 24/7 operation.
Security Systems	Physical (biometrics, CCTV) + logical (firewalls, encryption).

Data Center and Cloud Computing

Cloud providers use **globally distributed data centers** to deliver services.
Examples:

- **AWS Region:** A geographical area with multiple data centers (availability zones).
- **Azure Data Centers:** Built for redundancy, high availability, and low latency.

Types of Data Centers:

Type	Description
Enterprise Data Center	Owned/operated by companies for internal use.
Colocation Data Center	Rented space in a facility (shared infrastructure).
Cloud Data Center	Fully virtualized, operated by cloud providers (e.g., AWS).
Edge Data Center	Located near users for low-latency applications (IoT, 5G).

Key Features of Modern Data Centers:

- **Virtualization:** Allows multiple virtual machines on fewer physical servers.
- **Automation & Orchestration:** Tools for managing tasks, scaling, and updates.
- **Redundancy:** Duplicate systems to avoid downtime (e.g., N+1 power supply).
- **Energy Efficiency:** Green technologies to reduce energy use.
- **Security:** Multi-layer protection — physical + network + software.

Standards & Tiers (Uptime Institute):

Tier	Description	Uptime
I	Basic capacity	~99.67%
II	Redundant capacity components	~99.75%
III	Concurrently maintainable	~99.98%
IV	Fault-tolerant	~99.995%

Why Data Centers Matter in Cloud?

- **Scalability**: Easily add or remove resources.
- **Availability**: High uptime ensures 24/7 access.
- **Security**: Protect critical user and enterprise data.
- **Global Access**: Enable fast access to apps worldwide.

Real-World Example:

When you store a file in **Google Drive** or run a website on **AWS**, it is processed and stored in a **data center** located in a secure region (like Singapore, Frankfurt, Mumbai, etc.).

Networking Issues in Data Centers

Data centers rely on complex and high-speed networking systems to handle enormous amounts of data. However, several networking issues can impact **performance**, **reliability**, and **security** of data center operations.

Major Networking Issues in Data Centers:

1. Network Congestion

- **Cause:** High volume of data traffic from multiple virtual machines (VMs) or services.
- **Effect:** Increased latency, packet drops, and reduced throughput.
- **Solution:** Load balancing, Quality of Service (QoS), traffic engineering (e.g., SDN).

2. Latency

- **Cause:** Physical distance between devices or inefficient routing.
- **Effect:** Delayed responses in real-time applications (e.g., VoIP, gaming).
- **Solution:** Use of edge computing, optimized routing, and content delivery networks (CDNs).

3. Packet Loss

- **Cause:** Congestion, buffer overflow in switches/routers, or faulty hardware.
- **Effect:** Retransmissions and performance degradation.
- **Solution:** Redundant paths, better buffer management, ECMP (Equal-Cost Multi-Path Routing).

4. Scalability Challenges

- **Cause:** Increasing number of servers, VMs, and services in cloud environments.
- **Effect:** Routing table overload, difficulty in network configuration and management.
- **Solution:** Use of **software-defined networking (SDN)** and **automation tools** like Ansible.

5. Security Threats

- **Cause:** Attacks like DDoS, spoofing, or data interception.
- **Effect:** Service disruption, data breaches, or loss of trust.
- **Solution:** Firewalls, intrusion detection systems (IDS), network segmentation, and encryption.

6. Virtual Network Overhead

- **Cause:** Overuse of virtualization (e.g., virtual switches and routers).
- **Effect:** Additional processing delays, reduced network performance.
- **Solution:** Efficient virtual network function (VNF) placement and hardware acceleration.

7. Single Points of Failure (SPOF)

- **Cause:** Centralized components without redundancy.

- **Effect:** Entire network segment may go offline if a key device fails.
- **Solution:** Redundant paths, devices, and power supplies.

8. Inefficient Load Balancing

- **Cause:** Improper distribution of traffic across servers.
- **Effect:** Some servers get overloaded while others are underused.
- **Solution:** Use dynamic and intelligent load balancers (e.g., AWS ELB)

Transport Layer Issues in Data Center Networks (DCNs)

What is the Transport Layer?

The **Transport Layer (Layer 4)** in the OSI model ensures **reliable delivery** of data between end systems. In **Data Center Networks (DCNs)**, it manages connections between **virtual machines**, **containers**, and **services**—often with **high data volume** and **low latency requirements**.

Key Transport Layer Issues in DCNs

1. TCP Incast

- **Cause:** Multiple servers send data to a single receiver simultaneously (typical in parallel computing or storage access).
- **Effect:** Sudden **buffer overflow** at the switch → **packet loss**, **timeout**, **low throughput**.
- **Example:** Distributed file systems (like HDFS, GFS) accessing data from many nodes at once.
- **Solutions:**
  - Reduce TCP timeout (e.g., using **DCTCP**)
  - Use **explicit congestion notification (ECN)**
  - Increase buffer size at switches

2. Out-of-Order Packet Delivery

- **Cause:** Multi-path routing (ECMP) leads to packets arriving out of sequence.
- **Effect:** Receiver buffers packets or drops them → **delay** and **retransmission**.
- **Solution:** Use **flow hashing** or **transport protocols** that tolerate path variation (e.g., **MPTCP**).

---

3. High Latency and Jitter

- **Cause:** TCP congestion control is slow to adapt to fast-changing network loads in DCNs.
- **Effect:** Real-time applications (like video calls) suffer from **delay and jitter**.
- **Solution:** Use **DC-optimized transport protocols** (e.g., **HULL**, **DCTCP**) that maintain low queues.

4. Bufferbloat

- **Cause:** Excessive buffering in switches or end-hosts.

- **Effect: Increased latency** despite available bandwidth.
- **Solution:** Active queue management (e.g., **CoDel**, **RED**) to drop packets early.

5. Unfair Bandwidth Allocation

- **Cause:** Traditional TCP can favor some flows over others (e.g., short flows get stuck behind long flows).
- **Effect:** Starvation of latency-sensitive tasks.
- **Solution:** Use **priority-based flow control**, **short-flow prioritization**, or **Rate Control Protocols**.

6. Flow Collision and Congestion

- **Cause:** Too many flows converge on a single link or switch.
- **Effect:** Packet drops, retransmission, throughput collapse.
- **Solution: Congestion-aware routing** and **adaptive load balancing**.

UNIT V

Security in Cloud Computing, and Advanced Concepts in Cloud Computing

Security in Cloud Computing

Definition

Security in Cloud Computing refers to the **technologies, policies, controls, and procedures** that protect **data**, **applications**, and **infrastructure** associated with cloud environments from **unauthorized access**, **attacks**, and **data loss**.

Cloud security must cover all aspects: **network**, **storage**, **compute**, **identity**, and **compliance**.

Key Security Challenges in the Cloud:

Challenge	Description
Data Breaches	Unauthorized access to confidential data
Data Loss	Accidental deletion or corruption
Insecure APIs	Weak or poorly designed APIs can be exploited
Insider Threats	Malicious or careless users from within the organization
Account Hijacking	Attackers gaining control of cloud credentials
Denial of Service (DoS)	Overwhelms cloud services, making them unavailable
Misconfiguration	Default settings or improper setup of cloud services

---

Major Aspects of Cloud Security:

1. Data Security

- **Encryption at Rest**: Encrypting data stored on disk.
- **Encryption in Transit**: SSL/TLS for data in motion.
- **Tokenization**: Replacing sensitive data with tokens.

2. Identity and Access Management (IAM)

- Control **who** can access **what** in the cloud.
- Use of:
  - **Multi-Factor Authentication (MFA)**
  - **Role-Based Access Control (RBAC)**
  - **Least privilege principle**

3. Network Security

- Use of **firewalls**, **Virtual Private Clouds (VPCs)**, **VPNs**, **network ACLs**, and **intrusion detection/prevention systems (IDS/IPS)**.

4. Compliance and Legal

- Meeting legal standards like:
  - **GDPR**
  - **HIPAA**
  - **ISO/IEC 27001**

- SOC 2

5. Monitoring and Incident Response

- **Log analysis**, **anomaly detection**, and **SIEM tools**.
- Real-time alerts and incident response mechanisms.

6. Security for Virtualization & Containers

- Secure hypervisors, virtual machines, and containers (e.g., Docker, Kubernetes).
- Avoid VM escape, container breakout.

Advanced Concepts in Cloud Computing

These are **emerging or complex topics** that enhance the power, flexibility, and intelligence of cloud computing beyond basic IaaS, PaaS, and SaaS models.

1. Serverless Computing (Function as a Service – FaaS)

- **Definition**: Run functions without managing servers.
- **Example**: AWS Lambda, Azure Functions
- **Benefits**:
    - Pay only when the code runs
    - Auto-scaling
    - No server management

2. Edge Computing

- **Definition**: Processing data closer to the data source (edge of the network).
- **Used in**: IoT, autonomous vehicles, smart cities.
- **Benefits**:
    - Low latency
    - Reduced bandwidth
    - Real-time processing

3. Artificial Intelligence & Machine Learning in Cloud

- **Cloud AI services**: Google Cloud AI, AWS SageMaker, Azure ML
- **Benefits**:
    - Scalable AI training and inference
    - Pre-trained models
    - APIs for vision, language, etc.

4. Microservices Architecture

- **Definition**: Break down applications into smaller, independent services.

- **Runs on**: Containers (Docker), Kubernetes
- **Benefits**:
  - Easier updates
  - Fault isolation
  - Scalability

5. Containers & Kubernetes

- **Containers**: Lightweight, portable execution environments (e.g., Docker).
- **Kubernetes**: Orchestration tool to manage containers.
- **Benefits**:
  - Portability
  - Scalability
  - Faster deployment

6. Multi-Cloud & Hybrid Cloud

- **Multi-Cloud**: Using multiple public cloud providers (e.g., AWS + Azure)
- **Hybrid Cloud**: Combining on-premises and cloud infrastructure
- **Benefits**:
  - Redundancy
  - Flexibility
  - Avoid vendor lock-in

7. Infrastructure as Code (IaC)

- **Definition**: Manage cloud infrastructure through code.
- **Tools**: Terraform, AWS CloudFormation, Ansible
- **Benefits**:
  - Automation
  - Version control
  - Consistency

8. Cloud Security & Zero Trust Architecture

- **Zero Trust**: "Never trust, always verify"
- Focuses on identity, least privilege, segmentation.
- Enforces strong authentication and real-time threat detection.

9. Cloud Cost Optimization

- Techniques to reduce cloud bills:
  - Auto-scaling
  - Spot instances
  - Right-sizing resources
  - Cost monitoring tools (e.g., AWS Cost Explorer)

10. Cloud-native Development

- Design apps **specifically for the cloud**
- Uses: