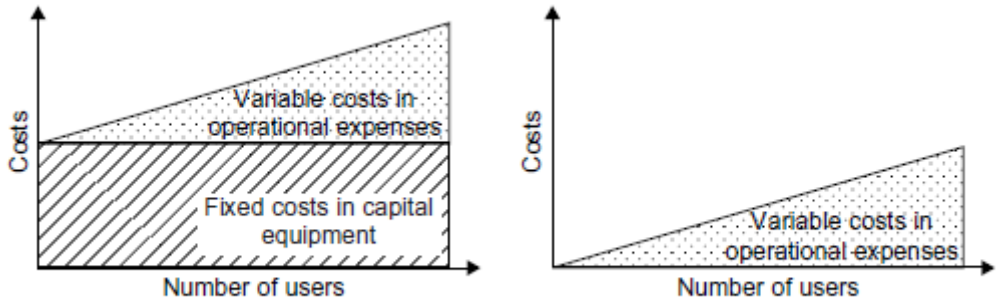
- Data privacy protection Can you trust data centers to handle your private data and records? This concern must be addressed to make clouds successful as trusted services.
- High quality of cloud services The QoS of cloud computing must be standardized to make clouds interoperable among multiple providers.
- New standards and interfaces This refers to solving the data lock-in problem associated with data centers or cloud providers. Universally accepted APIs and access protocols are needed to provide high portability and flexibility of virtualized applications

1.7 COST MODEL:

- ✓ In traditional IT computing, users must acquire their own computer and peripheral equipment as capital expenses. In addition, they have to face operational expenditures in operating and maintaining the computer systems, including personnel and service costs. The addition of variable operational costs on top of fixed capital investments in traditional IT. The fixed cost is the main cost, and that it could be reduced slightly as the number of users increases.The operational costs may increase sharply with a larger number of users. Therefore, the total cost escalates quickly with massive numbers of users.

- ✓ Cloud computing applies a pay-per-use business model, in which user jobs are outsourced to data centers. To use the cloud, one has no up-front cost in hardware acquisitions. Only variable costs are experienced by cloud users, Overall, cloud computing will reduce computing costs significantly for both small users and large enterprises. Computing economics does show a big gap between traditional IT users and cloud users. The savings in acquiring expensive computers up front releases a lot of burden for startup companies.



2. ARCHITECTURAL DESIGN OF COMPUTE AND STORAGE CLOUDS

An Internet cloud is envisioned as a public cluster of servers provisioned on demand to perform collective web services or distributed applications using data-center resources.

2.1 Cloud Platform Design Goals

- Scalability, virtualization, efficiency, and reliability are four major design goals of a cloud computing platform. Clouds support Web 2.0 applications.
- Cloud management receives the user request, finds the correct resources, and then calls the provisioning services which invoke the resources in the cloud.
- The cloud management software needs to support both physical and virtual machines.

2.2 A Generic Cloud Architecture

- The Internet cloud is envisioned as a massive cluster of servers. These servers are provisioned on demand to perform collective web services or distributed applications using data-center resources.
- The cloud platform is formed dynamically by provisioning or de-provisioning servers, software, and database resources. Servers in the cloud can be physical machines or VMs. User interfaces are applied to request services. The provisioning tool carves out the cloud system to deliver the requested service.
- The cloud computing resources are built into the data centers, which are typically owned and operated by a third-party provider.
- Consumers do not need to know the underlying technologies. In a cloud, software becomes a service. The cloud demands a high degree of trust of massive amounts of data retrieved from large data centers.
- We need to build a framework to process large-scale data stored in the storage system. This demands a distributed file system over the database system. Other cloud resources are added into a cloud platform, including storage area networks (SANs), database systems, firewalls, and security devices.
- Web service providers offer special APIs that enable developers to exploit Internet clouds.
- The software infrastructure of a cloud platform must handle all resource management and do most of the maintenance automatically.
- Software must detect the status of each node server joining and leaving, and perform relevant tasks accordingly. Cloud computing providers, such as Google and Microsoft, have built a large number of data centers all over the world.
- Each data center may have thousands of servers. The location of the data center is chosen to reduce power and cooling costs. Thus, the data centers are often built around hydroelectric power

2.3 LAYERED CLOUD ARCHITECTURAL DEVELOPMENT:

- The architecture of a cloud is developed at three layers: infrastructure, platform, and application
- These three development layers are implemented with virtualization and standardization of hardware and software resources provisioned in the cloud.

- The services to public, private, and hybrid clouds are conveyed to users through networking support over the Internet and intranets involved.
- It is clear that the infrastructure layer is deployed first to support IaaS services. This infrastructure layer serves as the foundation for building the platform layer of the cloud for supporting PaaS services.
- The platform layer is a foundation for implementing the application layer for SaaS applications. Different types of cloud services demand application of these resources separately.
- The infrastructure layer is built with virtualized compute, storage, and network resources. The abstraction of these hardware resources is meant to provide the flexibility demanded by users.
- virtualization realizes automated provisioning of resources and optimizes the infrastructure management process.
- The platform layer is for general-purpose and repeated usage of the collection of software resources. This layer provides users with an environment to develop their applications, to test operation flows, and to monitor execution results and performance.

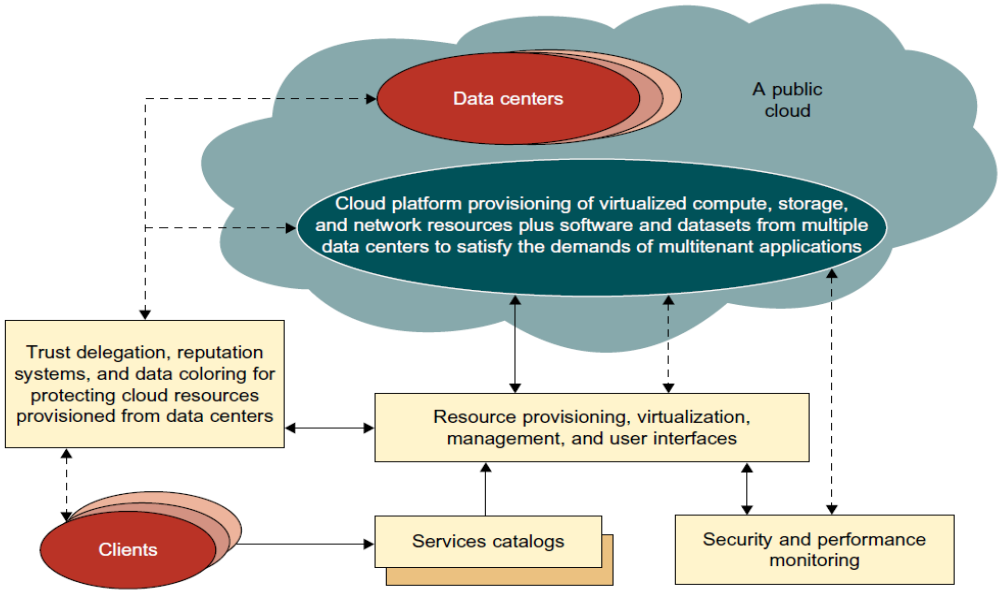


FIGURE 4.14

A security-aware cloud platform built with a virtual cluster of VMs, storage, and networking resources over the data-center servers operated by providers.

- The platform should be able to assure users that they have scalability, dependability, and security protection. In a way, the virtualized cloud platform serves as a "system middleware" between the infrastructure and application layers of the cloud application layer is formed with a collection of all needed software modules for SaaS applications.

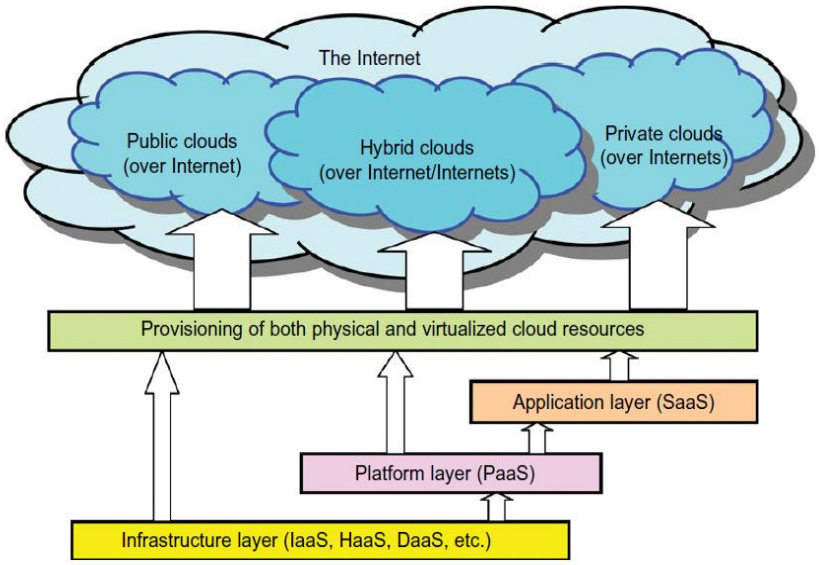


FIGURE 4.15

Layered architectural development of the cloud platform for IaaS, PaaS, and SaaS applications over the Internet.

- Service applications in this layer include daily office management work, such as information retrieval, document processing, and calendar and authentication services.
- The application layer is also heavily used by enterprises in business marketing and sales, consumer relationship management (CRM), financial transactions, and supply chain management. It should be noted that not all cloud services are restricted to a single layer. Many applications may apply resources at mixed layers. After all, the three layers are built from the bottom up with a dependence relationship.
- From the provider's perspective, the services at various layers demand different amounts of functionality support and resource management by providers. In general, SaaS demands the most work from the provider, PaaS is in the middle, and IaaS demands the least.

2.4 VIRTUALIZATION SUPPORT AND DISASTER RECOVERY

- One very distinguishing feature of cloud computing infrastructure is the use of system virtualization and the modification to provisioning tools. Virtualization of servers on a shared cluster can consolidate web services.
- As the VMs are the containers of cloud services, the provisioning tools will first find the corresponding physical machines and deploy the VMs to those nodes before scheduling the service to run on the virtual nodes.
- In addition, in cloud computing, virtualization also means the resources and fundamental infrastructure are virtualized. The user will not care about the computing

resources that are used for providing the services. Cloud users do not need to know and have no way to discover physical resources that are involved while processing a service request.

2.5 VM CLONING FOR DISASTER RECOVERY

- VM technology requires an advanced disaster recovery scheme. One scheme is to recover one physical machine by another physical machine. The second scheme is to recover one VM by another VM.
- Traditional disaster recovery from one physical machine to another is rather slow, complex, and expensive. Total recovery time is attributed to the hardware configuration, installing and configuring the OS, installing the backup agents, and the long time to restart the physical machine.
- To recover a VM platform, the installationand configuration times for the OS and backup agents are eliminated. Therefore, we end up with a much shorter disaster recovery time, about 40 percent of that to recover the physical machines.
- Virtualization aids in fast disaster recovery by VM encapsulation. The cloning of VMs offers an effective solution. The idea is to make a clone VM on a remote server for every running VM on a local server. Among all the clone VMs, only one needs to be active.
- The remote VM should be in a suspended mode. A cloud control center should be able to activate this clone VM in case of failure of the originalVM, taking a snapshot of the VM to enable live migration in a minimal amount of time. The migrated VM can run on a shared Internet connection. Only updated data and modified states are sent to the suspended VM to update its state. The Recovery Property Objective (RPO) and Recovery TimeObjective (RTO) are affected by the number of snapshots taken. Security of the VMs should be enforced during live migration of VMs.

2.6 ARCHITECTURAL DESIGN CHALLENGES

Challenge 1—Service Availability and Data Lock-in Problem

- The management of a cloud service by a single company is often the source of single points of failure.
- To achieve HA, one can consider using multiple cloud providers. Even if a company has multiple datacenters located in different geographic regions, it may have common software infrastructure and accounting systems. Therefore, using multiple cloud providers may provide more protection from failures.
- Another availability obstacle is distributed denial of service (DDoS) attacks. Criminals threaten to cut off the incomes of SaaS providers by making their services unavailable. Some utility computing services offer SaaS providers the opportunity to defend against DDoS attacks by using quick scale-ups.

- Software stacks have improved interoperability among different cloud platforms, but the APIs itself are still proprietary. Thus, customers cannot easily extract their data and programs from one site to run on another. The obvious solution is to standardize the APIs so that a SaaS developer can deploy services and data across multiple cloud providers. This will rescue the loss of all data due to the failure of a single company.

Challenge 2—Data Privacy and Security Concerns

- Current cloud offerings are essentially public (rather than private) networks, exposing the system to more attacks. Many obstacles can be overcome immediately with well-understood technologies such as encrypted storage, virtual LANs, and network middleboxes (e.g., firewalls, packet filters).
- SaaS providers to keep customer data and copyrighted material within national boundaries.
- Traditional network attacks include buffer overflows, DoS attacks, spyware, malware, rootkits, Trojan horses, and worms.
- In a cloud environment, newer attacks may result from hypervisor malware, guest hopping and hijacking, or VM rootkits. Another type of attack is the man-in-the-middle attack for VM migrations. In general, passive attacks steal sensitive data or passwords. Active attacks may manipulate kernel data structures which will cause major damage to cloud servers

Challenge 3—Unpredictable Performance and Bottlenecks

- Multiple VMs can share CPUs and main memory in cloud computing, but I/O sharing is problematic.
- One solution is to improve I/O architectures and operating systems to efficiently virtualize interrupts and I/O channels.
- Internet applications continue to become more data-intensive. If we assume applications to be
- "pulled apart" across the boundaries of clouds, this may complicate data placement and transport.
- Cloud users and providers have to think about the implications of placement and traffic at every level of the system, if they want to minimize costs. This kind of reasoning can be seen in Amazon's development of its new CloudFront service.
- Therefore, data transfer bottlenecks must be removed, bottleneck links must be widened, and weak servers should be removed

Challenge 4—Distributed Storage and Widespread Software Bugs

- The database is always growing in cloud applications. The opportunity is to create a storage system that will not only meet this growth, but also combine it with the cloud advantage of scaling arbitrarily up and down on demand.

- This demands the design of efficient distributed SANs. Data centers must meet programmers' expectations in terms of scalability, data durability, and HA. Data consistence checking in SAN-connected data centers is a major challenge in cloud computing.
- Large-scale distributed bugs cannot be reproduced, so the debugging must occur at a scale in the production data centers. No data center will provide such a convenience.
- One solution may be a reliance on using VMs in cloud computing. The level of virtualization may make it possible to capture valuable information in ways that are impossible without using VMs. Debugging over simulators is another approach to attacking the problem, if the simulator is well designed.

Challenge 5—Cloud Scalability, Interoperability, and Standardization

- The pay-as-you-go model applies to storage and network bandwidth; both are counted in terms of the number of bytes used. Computation is different depending on virtualization level.
- GAE automatically scales in response to load increases and decreases; users are charged by the cycles used. AWS charges by the hour for the number of VM instances used, even if the machine is idle. The opportunity here is to scale quickly up and down in response to load variation, in order to save money, but without violating SLAs.
- Open Virtualization Format (OVF) describes an open, secure, portable, efficient, and extensible format for the packaging and distribution of VMs. It also defines a format for distributing software to be deployed in VMs. This VM format does not rely on the use of a specific host platform, virtualization platform, or guest operating system. The approach is to address virtual platform-agnostic packaging with certification and integrity of packaged software. The package supports virtual appliances to span more than one VM.
- OVF also defines a transport mechanism for VM templates, and can apply to different virtualization platforms with different levels of virtualization. In terms of cloud standardization, we suggest the ability for virtual appliances to run on any virtual platform. We also need to enable VMs to run on heterogeneous hardware platform hypervisors. This requires hypervisor-agnostic VMs.

Challenge 6—Software Licensing and Reputation Sharing

- Many cloud computing providers originally relied on open source software because the licensing model for commercial software is not ideal for utility computing.
- The primary opportunity is either for open source to remain popular or simply for commercial software companies to change their licensing structure to better fit cloud computing.

- One can consider using both pay-for-use and bulk-use licensing schemes to widen the business coverage. One customer's bad behavior can affect the reputation of the entire cloud. For instance, blacklisting of EC2 IP addresses by spam-prevention services may limit smooth VM installation.
- An opportunity would be to create reputation-guarding services similar to the "trusted e-mail" services currently offered (for a fee) to services hosted on smaller ISPs. Another legal issue concerns the transfer of legal liability.
- Cloud providers want legal liability to remain with the customer, and vice versa. This problem must be solved at the SLA level.

3. PUBLIC CLOUD PLATFORMS: GAE, AWS, AND AZURE

- Cloud services are demanded by computing and IT administrators, software vendors, and end users. We have five levels of cloud players.
- At the top level, individual users and organizational users demand very different services. The application providers at the SaaS level serve mainly individual users. Most business organizations are serviced by IaaS and PaaS providers.
- The infrastructure services (IaaS) provide compute, storage, and communication resources to both applications and organizational users. The cloud environment is defined by the PaaS or platform providers. Note that the platform providers support both infrastructure services and organizational users directly.
- Cloud services rely on new advances in machine virtualization, SOA, grid infrastructure management, and power efficiency. Consumers purchase such services in the form of IaaS, PaaS, or SaaS as described earlier.
- Many cloud entrepreneurs are selling value-added utility services to massive numbers of users. The cloud industry leverages the growing demand by many enterprises and business users to outsource their computing and storage jobs to professional providers. The provider service charges are often much lower than the cost for users to replace their obsolete servers frequently.