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Pillars of Cloud Computing: A Review

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Abstract--- Nowadays cloud computing is acquiring great deal of attention in users, markets, education and publications. Cloud is a group of servers that provide highly scalable services like SaaS, PaaS, IaaS to transform computing in business. Information stored in clouds is accessible from anywhere at any time. Cloud providers have storage, software and infrastructure facilities to run businesses effectively. Cloud computing is a dominant technology that facilitates businesses to become more connective, scalable, collaborative, real-time and productive. Cloud computing is based on the concept of virtualization and hence eliminates the need of a powerful configuration deployment by providing services at a reasonable price and hence this technology is very helpful for small organizations that cannot afford the cost of infrastructure and storage space. This robust technology has shifted the cost of managing hardware, software and computational infrastructure to third parties such as Google, Microsoft, Amazon. By shifting the costs of managing computational infrastructure to third parties, cloud computing has made it possible for individuals and small organizations to deploy world-wide services; all they need to pay is the marginal cost of actual resource usage. As all the data is being stored in clouds, security issues should be addressed properly. All the organizations have concerns about security, privacy, residency, unauthorized access, interception, interruption, modification, fabrication and non-repudiation. Security system of clouds should not be vulnerable to unauthorized data manipulation. By effectively implementing the pillars of cloud computing security of data over clouds could be ensured. This paper describes pillars, service models, deployment models and challenges of cloud computing to provide a better and common understanding of the subject.

Keywords: Cloud Computing, SaaS, PaaS, IaaS, Agility, Parallel, Distributed, Scalable, Modular, Service-Oriented.

I. INTRODUCTION

Cloud Computing has changed the way how people use technology without investing in new infrastructure facilities, training new personnel or procuring new software. Cloud is an impactful technology that provides on-demand access to computing resources at a marginal and predictable cost. Cloud computing is a recent dominant technological development widely accepted by organizations, educational institutions and individual users. Cloud computing adds a new dimension to business models by eliminating the need of a powerful physical configuration. Cloud computing allows consumers to use services like software, platform and infrastructure as a supplement to consumer's on-premises infrastructure without installation of costly hardware and software. Concept of cloud computing is same as accessing e-mails. Like e-mails, cloud services can be accessed with the help of Internet. Cloud computing is also an Internet-based service. Service providers of cloud process, manage and store the consumer's data at a remote location. E-mail services provided by yahoo, gmail and rediffmail cloud service providers is a very simple and easily understandable example of cloud service. IT staff can spend valuable time on strategic activities rather than on routing maintenance of e-mail servers. E-mail management and storage is on the cloud, subscribers do not have e-mails on their personal computer rather they can access their e-mails with the help of an Internet connection. Internet connection is the only requirement which an organization need to have in order to access cloud. Consumers of cloud services are required to pay-as-per-usage not more than that. Cloud Computing is an emerging technology that have a multiplying effect because it provides virtualized services like software, platform and infrastructure without physical installation of costly hardware and software. Cloud computing is agile, distributed, modular, parallel, scalable, service-oriented and secure.

II. CLOUD DEPLOYMENT MODELS

A. Public Cloud

Public clouds are available for general public. Public cloud's infrastructure is available for all the subscribers having an Internet connection and access to cloud space. Public clouds are more vulnerable than private clouds. Level of efficiency in resource sharing is highest in public clouds. A public cloud does not mean that user's data is accessible to all; vendors of public clouds provide an effective access control mechanism to ensure the integrity of data [1].

B. Private Cloud

Private clouds are available solely for a single group or organization. Access to private cloud's infrastructure is limited to that particular group or organization. This deployment model is implemented solely for an organization and is managed by either organization or third party [2]. Level of security is highest in private clouds.

C. Community Cloud

Community clouds are shared by several organizations having similar cloud requirements such as security concerns, policies and facilities etc. Organizations having common concerns opt for community clouds rather than using public clouds or creating their private clouds [3]. Management of community clouds is very complex.

D. Hybrid Cloud

Hybrid clouds are combinations of infrastructure of two or more clouds that is private, public or community. Organizations may host critical applications with rigorous security on private clouds and applications with less security concerns on the public cloud. Hybrid clouds facilitate “cloud bursting” which means if an application of private cloud needs additional resources, it can use the resources of public cloud in case of peak load requirements [4]. This resource sharing facilitates efficient utilization of resources among different clouds but increases the design complexity.

III. CLOUD SERVICE MODELS

A. Software as a service (SaaS)

Software is delivered as a service to the customer, which makes it unnecessary to have a physical copy of the software on all the devices of an organization. Some software services are free like Google, Hotmail while others are available on a subscription basis. Customers can have access to the software at all the times without worrying about deployment and maintenance of software. In this type of service customers have least control over the cloud. Examples of SaaS vendors are: SAP, Birst, Cloudphysics, Databricks, Hubspot, Netsuite, New Relic, Otixo, Qlik, Qubole, Salesforce.com, Salsify, ServiceNow, Snowflake Computing, Soonr, Splunk, Strevus, SumAll, Treasure Data, Xplenty etc.

B. Platform as a service (PaaS)

Tools, components and a development environment are delivered as a service to the customer, which help the customers to develop, test and operate web-based applications over the Internet. Customers can use the platform such as Windows Azure, Google AppEngine and Force.com and pay accordingly. Cloud computing platforms facilitate the users to create software applications by using the tools provided by cloud provider. PaaS providers offer services like operating system, server software, database management system, tools for design and development etc. to create scalable, service-oriented applications with lower investments. Examples of PaaS vendors are: Amazon EC2, Appistry, AppScale, AT&T, Engine Yard, Enomaly, FlexiScale, GCloud3, Gizmox, GoGrid, Google, LongJump, Microsoft, OrangeScape, RackSpace, Salesforce.com, Terremark, Ubuntu, Verizon etc.

C. Infrastructure as a service (IaaS)

IaaS providers offer services like storage, disaster recovery, remote access, backup, file sharing, resources and computing power to the customer on pay-per-usage basis. Amazon is the major player in this domain, it offers two products: EC2 (Elastic Compute Cloud) for computing resources and S3 (Simple Storage Services) for data storage.

Cloud computing provides highly scalable, virtualized, standardized, reliable, secure and dynamic infrastructure services to facilitate the working of small and large organizations that cannot afford the costly infrastructure. Organizations can focus on their application logic rather than installing their own infrastructure services. In cloud computing, instead of fixed resources, resources can grow—and shrink—dynamically as requirements shift and the customers pay on the basis of pay-per-usage. Examples of IaaS vendors are: AllenPort, Amazon, AppZero, Boomi, Cast Iron, Citrix Cloud Center (C3), Elastra, IBM, Informatica, New Relic, Novell, OpSource, RightScale, Stoneware, Carbonite, Ctera, IBM, Intronis, Robobak, Symantec etc.

IV. PILLARS OF CLOUD COMPUTING

Pillars are the foundational building blocks of cloud computing. If all the pillars of cloud computing are not implemented properly then that service cannot be considered as cloud computing service.

A. Dynamic Computing Infrastructure

Clouds should provide a standardized, scalable, robust and secure physical infrastructure in a virtualized manner. Dynamic means resources should be allocated and released as per the user’s requirements to match the traffic demand curve. This rapid elasticity of cloud computing facilitates the resources to grow-and-shrink automatically as per the customer’s requirements.

B. On-Demand Self-Service

Cloud Computing has changed the way how people use technology. Cloud computing technology provides convenient on-demand access to a shared pool of resources without human intervention on the cloud service provider’s side. Users are able to provision and release cloud computing resources on their own through a web-based self-service portal or control panel with a simple user interface, hence making users to be more independent of cloud service providers. Users can request for the resources on demand and resources are provisioned and released in a very simple way. User’s requests are automatically processed by the cloud infrastructure without human intervention on the cloud provider’s side [5]. Users have the power to change cloud services as per need through an online easy-to-use control panel. Example of Cloud service providers providing on-demand self-services are: Amazon Web Services (AWS), Microsoft, Google, IBM, Salesforce.com etc.

C. Distributed and Parallel Computing

In clouds, distributed and parallel computing allows to use standardized, reliable and virtualized limitless pool of computing power rather than being confined to a limited number of servers. In cloud computing, servers work on each task asynchronously rather than synchronously and hence results in a comparatively faster and efficient completion time of tasks. Message queue systems are used for routing the tasks to the servers, for allocating computational tasks and exchanging data among cloud processes in distributed computing. In a message queue system, all the servers can be scaled as needed to perform tasks. Commonly used Message queue systems are Amazon Simple Queue Service (SQS), RabbitMQ, ActiveMQ, ZeroMQ, IronMQ and Rackspace cloud queues etc.

D. Consumption-Based Billing (Measured Service)

Customers of cloud computing are required to pay only as per the usage. Resources of clouds could be provisioned and de-provisioned as per the requirements of customer. Clouds should keep the proper track of resource usage for billing; customers are required to pay only for the resources they use not more than that. Instead of guessing, the resource usage should be optimized, measured, monitored, reported and controlled for providing a transparent environment for both the cloud provider and consumer.

E. Modular Design and Service-Oriented Architecture

In clouds, all the servers (Varnish caching servers, web servers, application servers and database servers) are decoupled so that application becomes more scalable and replaceable. This modular design makes overall processing simpler and easier to maintain. All the applications are divided into different services and the services that have distinct roles are isolated from each other to improve the overall performance of the application.

F. Horizontal Scaling with Stateless Applications

In clouds, each request happens in isolation. The underlying architecture of clouds doesn't care about the origin and destination of a request. All the requests are handled separately. The server doesn't store the information regarding the state of a user, which facilitates the infrastructure of a stateless application to scale infinitely. Since there is no need to store the states, servers could be scaled horizontally (adding more servers as per requirement) rather than vertically (adding more RAM or other resources on a single server). Stateless applications follow the concepts of modularity (functional independence) which allow the different services in the application to scale independently of one another. All the applications use security tokens to authenticate the users. Unlike passwords, security tokens are physical objects such as a card or key fob which provide an extra level of security in a distributed architecture through two-factor authentication. In two-factor authentication process, one factor is a small hardware device such as a card and the other factor is a security code such as PIN (Personal Identification Number) which is memorized by the users.

G. Broad Network Access

Broad network access means cloud's resources are accessible from different devices (thin or thick clients) and locations. Resources on cloud are available for access from a wide range of devices such as workstations, laptops, tablets, smart phones and other devices.

H. Becoming Agile During Different Demand Curves

Agility offered by cloud computing providers is a very true advantage for users. Cloud computing and agility are synonyms. Agility means the capability of rapidly, timely and cost efficiently adapting to dynamic scenarios of changing requirements. In cloud computing users can access the resources from shared pool of resources as per requirement and release the resources when they are not needed means resources can grow and shrink as per need. Cloud computing provides the same level of service to consumers by allowing an application to become aware of its environment and scale the configuration as traffic exceeds defined limits. Multiple cloud resources can be dynamically added and removed to manage the traffic of requests. In traditional computing models, same number of resources (like servers, networks, storage etc.) remain online at all the times, which leads to wastage of resources as some resources are over-burdened and others are not being utilized to their full potential. Cloud computing overcomes this problem as it relies on sharing of resources which are dynamically allocated and reallocated according to changing traffic patterns of customer's requirements, hence maximizing the efficient utilization of resources.

I. Resource Pooling

Resource pooling differentiates the traditional and cloud computing approach. In cloud computing, different strategies are being used for managing and categorizing the resources. Instead of dedicated resources, customers of clouds can share the servers, networks, storage, bandwidth and information from a common pool. These resources can be allocated and released to suit the customer's requirements without any changes being visible to the customer. Resource pooling creates a sense of availability of infinite resources which are scalable and immediately available to meet the demand of customers.

J. Security in the Cloud

Security is the most crucial aspect for any form of computing, making it an obvious expectation that security issues are critical for cloud computing environment as well. All the data is being stored on someone else's premise or network so

security of user’s data in clouds is a critical issue [6]. Various security threats in clouds are traffic eavesdropping, malicious intermediary, interception, modification, interruption, denial of service, insufficient authorization, virtualization attack and overlapping trust boundaries. Security means “keeping your application secure against threats in the cloud”. As more and more of data is being stored in the clouds, exposure to data manipulation or leakage increases. All the services of cloud computing are distributed and service-oriented by nature. In security models of cloud authentication database, front-end and users are shielded because all the applications are divided into different services. All the requests are passed via REST API to incorporate more control over access to particular services. Architecture of REST is scalable for services (like Facebook, Twitter, LinkedIn, Pinterest, Google+ and newsgroups etc.) that are accessible via Internet. Clouds provide better security because in clouds users interact with dumb front-end servers and front-end servers interact with the authentication servers; authentication API and code are hidden from users. In addition to this cloud security vendors are offering authentication and log management technologies, encryption and decryption techniques, spam filters, cloud-based antivirus, web scanning engines, social network security, HIPAA (Health Insurance Portability and Accountability Act) compliance, PCI (Payment Card Industry) compliance and cloud-based DLP (Data Loss Prevention) to protect the confidential information by inspecting the Internet traffic. This makes the job of unauthorized users difficult who are looking for the vulnerabilities in the application. Examples of cloud security vendors are: Symantec, WatchGuard, McAfee, Barracuda, M86, Cisco, AppRiver, HP Application Security Center, Panda, Ping, Proofpoint, Qualys, ScanSafe, StillSecure, Symplified, SyferLock, Trend Micro, Webroot, Websense, WhiteHat, Zscaler etc.

Table 1 Pillars of Cloud Computing

Dynamic Computing Infrastructure	By implementing this pillar of cloud computing, resources can be allocated and released as per the consumer’s demand.
On-Demand Self-Service	By implementing this pillar of cloud computing, users can provision and release cloud’s resources on their own through a web-based self-service portal or control panel with a simple user interface, hence making users to be more independent of cloud service providers.
Distributed and Parallel Computing	By implementing this pillar of cloud computing, more requests of computations can be executed in comparatively less time.
Consumption-Based Billing (Measured Service)	By implementing this pillar of cloud computing, cloud providers keep the proper track of resource usage for billing; customers are required to pay only for the resources they use not more than that.
Modular Design and Service-Oriented Architecture	By implementing this pillar of cloud computing, risk of tight coupling that sometimes led to domino-style cascade could be alleviated.
Horizontal Scaling with Stateless Applications	By implementing this pillar of cloud computing, different services in the application could be scaled independently of one another and an efficient two-factor token-based security mechanism could be applied on all the applications.
Broad Network Access	By implementing this pillar of cloud computing, cloud’s resources can be made accessible from different devices (like workstations, laptops, tablets, smart phones) and locations.
Becoming Agile During Different Demand Curves	By implementing this pillar of cloud computing, elasticity could be added in the application which allows us to add and subtract servers in a way that mimics the traffic demand curve.
Resource Pooling	By implementing this pillar of cloud computing, customers of clouds can share the servers, networks, storage, bandwidth and information from a common pool.
Security in the Cloud	By implementing this pillar of cloud computing, authentication API and code of application could be secured from unauthorized users who want to gain access to scan the system for vulnerabilities.

Other pillars of cloud computing are rapid elasticity, location-independent resource pooling, virtualization, automation, end-to-end monitoring etc. So, Cloud Computing is agile, scalable, modular, service-oriented, distributed, measured, on-demand, dynamic and elastic computing using pooled resources, usually on the Internet.

V. CHALLENGES OF CLOUD COMPUTING

Nowadays companies are aware of the added business value provided by the cloud computing but security of data stored in clouds is the major challenge for cloud service providers. Organizations have very less control over off-premise storage of data. Many organizations are delaying their move to cloud because of security issues. Information stored in the clouds is more vulnerable to security threats and attacks. All the information can be accessed with the help of Internet, which creates a very risky environment. The critical issues such as reliability, trust, confidentiality, integrity and availability should be resolved to ensure the security of data. Storing valuable confidential data on someone else's server is not secured until and unless cloud providers develop intensive security mechanisms against all security threats. So the decision of out-sourcing of data in clouds should be balanced with the security issues. For a smooth transition to cloud computing, a thorough understanding of benefits and challenges of the subject is needed. All the following challenges should be considered for smooth transition to clouds.

A. Security and Privacy

Security is one of the major challenge in cloud adoption which diminishes the growth of cloud computing. Despite of all the benefits provided by cloud computing providers, many leading companies are delaying their transition to cloud because of security and privacy concerns. As more and more data is being placed in clouds, security and privacy concerns are also growing. Modification, fabrication, hacking, cracking, interception, interruption and other security attacks (like Denial of service, side channel, authentication, man-in-the-middle cryptographic attacks) to cloud infrastructure would affect multiple clients even if only one site is attacked [7].

B. Reliability and Availability

Reliability and availability are the major issues which should be considered to provide effective round-the-clock services to the customers. Cloud providers still lack in providing services without disruption which results in frequent outages, backdoors, eavesdropping, exploits, denial of service attacks, performance slowdowns etc.

C. Interoperability and Portability

Interoperability and Portability are essential for cloud computing. All the levels of interoperability are essential. First, to integrate cloud services with an organization's on-premise IT. Secondly, to integrate services of different cloud vendors simultaneously whenever there is a need. Nowadays, each cloud vendor has its own way of interacting and offering services which makes it very difficult to integrate cloud services with an organization's own existing legacy systems, to work with platforms of different vendors simultaneously as needed, to migrate between different clouds and to integrate services of different cloud vendors. This vendor locking makes the transition of users among different cloud service providers difficult and leads to "Hazy Cloud" phenomenon [8]. "Hazy Cloud" phenomenon prohibits the users to provision resources from different vendors simultaneously which leads to inefficient utilization of cloud's resources.

D. Scalability and Elasticity

Scalability means resources can be provisioned as per the requirement; it is the ability of the system to perform well when there is demand for more resources. Elasticity means the ability to scale resources up and down to match the traffic demand curve. Elasticity enables scalability which means user can scale up or down the level of services. Scalability can be provided in two ways- horizontally and vertically. Horizontal scalability means addition of more nodes and vertical scalability means addition of more resources to a single node. Scalability and elasticity make the cost analysis a lot more complicated.

E. Network Performance and Bandwidth cost

Network performance and bandwidth cost are critical to cloud success. Performance of cloud computing services depends on the performance of underlying network that supports them. This means cloud-based services (like on-demand computing power, flexibility, agility etc.) are only as good as the underlying network connections. Organizations can save money on infrastructure but they have to spend for bandwidth cost as-per-usage. Complex data requires sufficient bandwidth over the network which increases the bandwidth cost. Many organizations are delaying their transition to clouds because of bandwidth cost.

F. Service Delivery and Billing

Cloud computing is gaining popularity because it provides on-demand access to a large pool of resources which allows the end user to take advantage of hardware, software, bandwidth, servers and storage via Internet. Customers pay only for the resources they use. But, it is very difficult to estimate the costs involved because of virtualization and on-demand nature of cloud computing. Cloud consumers do not have control over the resources provided by cloud service providers but they need the guarantee to ensure the quality, availability and performance of these resources after migration of their core businesses to clouds [9]. So, cloud providers create Service Level Agreements (SLAs) to measure the service and performance, but SLAs does not provide any guarantee for the availability and scalability of cloud resources because of on-demand nature of cloud computing. In cloud computing users are free to integrate the services of different cloud vendors so it becomes very difficult to keep track of costs involved. Also organizations would not shift to cloud without a service quality guarantee which includes availability, response time, uptime and scalability of resources.

VI. CONCLUSION

Nowadays companies are shifting to cloud computing and are aware of the business value that cloud computing brings to their businesses. But for a smooth transition an intelligent and strategic approach should be followed which entails comprehensive understanding of the benefits, pillars and challenges of cloud computing. Rather than moving everything to cloud, organizations can plan for using a hybrid approach, keeping sensitive confidential data on on-premise servers (organization's infrastructure) and other data on off-premise servers (cloud's infrastructure) because cloud servers can go down at any time. Security is the main pillar (foundational building block) of cloud computing. Compatibility of cloud applications of an organization with the cloud infrastructure in terms of login procedure, authentication, encryption and decryption can solve the problem of integrity and security of data. Leading cloud providers are deploying advanced security tools and procedures for providing better security to off-premise data in clouds. By bridging the gap between application vendor and cloud vendor problem of security can be solved. All the pillars should be implemented properly for producing a perfect cloud to help businesses in reducing costs, keeping operating costs low, increasing agility and minimizing the IT administrative effort. Cloud computing adoption is not free from issues and challenges. All the challenges must be addressed seriously for proper implementation of cloud computing technology.

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