Cloud Computing: History and Overview

Jayachander Surbiryala, Chunming Rong
Department of Electrical Engineering and Computer Science
University of Stavanger, Stavanger, Norway
{jayachander.surbiryala, chunming.rong}@uis.no

***Abstract*—Cloud computing has emerged as a new technology and business paradigm in the last couple of years. Cloud computing platforms provide easy access, scalability, reliability, reconfigurability, and high performance from its resources over the Internet without complex infrastructure management by customers. This article presents, a brief history of cloud computing from 1961 when McCarthy at MIT introduced about cloud computing, the evolution of cloud computing from its predecessors such as Utility computing and Grid computing, and development of cloud computing. We have also presented various directions in cloud computing along with advantages, cloud-centric design, mobile cloud, and security. It covers the characteristics, service models, and deployment models of cloud computing. We have presented the applications and security aspects associated with cloud computing.**

I. Introduction

Cloud computing is a model where services are added on the way to use the services over the Internet which are dynamically scaled. In the past, the cloud was often used to represent part of the Internet with some infrastructure. Nowadays Cloud is used as a metaphor for the services provided over the Internet. The rapid evolution of cloud services, cloud computing now supports a large number of operations in a fraction of seconds compared to traditional systems where the number of transactions was limited. This computational power can be used for anything such as pre-processing, analysis, and forecasting of future events. To use cloud services users still need to connect with their devices to access and work on these virtual devices with massive processing power around world [1].

Cloud computing is nothing but the integration of Distributed Computing, Parallel Computing, Utility Computing along with Network Storage, Virtualization, Load Balance, High Available, and various other related technologies. Cloud computing is defined in several ways, but National Institute of Standards and Technology (NIST) defines that "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" [2].

Cloud computing is an add-on, usage, and delivery of resources or services over the Internet that typically involves dynamic scaling of physical resources or virtualized resources. As per NIST definition of Cloud Computing, it should be convenient, usable, on-demand computing services, servers, storage space, software applications, services over the Internet with no or little interaction with the cloud service provider. Ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction.

With the rapid adoption of cloud computing applications and the Internet of Things (IoT), there is an increasing demand for Big Data storage and processing. Many of the users and small organizations are also looking for significant computing power and high availability.

Cloud computing is often confused with grid computing, utility computing, and autonomic computing. Grid computing is a distributed computing system where a group of computers coupled to form a virtual machine to perform large tasks [3]. Utility computing is a method of packaging several services such as facilities, storage, and so on for billable IT resources [4]. Autonomic computing is a system that has self-management capabilities [5]. Cloud computing capabilities depend on the clusters deployed (grid computing) with various functionalities of Utility and Autonomic computing.

Main contributions of this paper is, it gives a general introduction to cloud computing along with brief history, evolution, development, applications, and security aspects of cloud computing.

The rest of this paper is organized as follows: Section II presents the brief history of cloud computing and Section III talks about the evolution of cloud computing from it's predecessors utility computing and grid computing. In Section IV, development of cloud computing is presented along with fundamental characteristics, delivery models, and deployment models. We have discussed cloud applications and security in Section V and Section VI respectively. Finally, Section VII draws the conclusion.

II. Brief history

Evolution of the cloud computing can be mapped back to older systems which have been used in the real-time long before cloud computing has come into existence. In "Cloud Computing", the word "Cloud" means carrier or provider who provides the services over the Internet. "Computing" is the processing or computations or calculations or various resources that are provided by computer. The concept of cloud computing traces back to 1961 by John McCarthy at MIT: "If computers of the kind I have advocated become the computers of the future, then computing may someday be organized as a public utility just as the telephone system is a public utility.

978-1-7281-3101-6/19/$31.00 ©2019 IEEE
DOI 10.1109/CloudSummit47114.2019.00007

The computer utility could become the basis of a new and important industry." [6]

One of the first companies to start working with the concept of the "cloud computing" is formed by Salesforce in late 1990 [7]. The company started providing their Software as a Service (SaaS), which provides customer relationship management for its users. Salesforce model is one of the typical patterns of cloud computing, in addition to "Platform as a Service" (PaaS), which provides customers with development platform such as Microsoft Azure [8] and Google's Application Engine [9]. The other form is "Infrastructure as a Service" (IaaS) model such as Amazon Elastic Compute Cloud (EC2) started in 2006 [10].

In 2007, many of the US universities started collaborating with Google and IBM and promoted cloud computing programs at their universities. This helped reduce the cost for academic research, sharing the resources between the students, and to build substantial processing power or computing power to access it over the Internet. Many more universities around the globe followed the same trend during the subsequent years [11].

In July 2010, NASA and Rackspace started a joint project called OpenStack with several vendors including AMD, Intel, and Dell. Later on, many other organizations have joined the project. A non-profit organization called OpenStack Foundation is formed in September 2012 to promote OpenStack [12]. Now more than 500 companies are supporting the project [13]. Around 6800 companies are using OpenStack to deploy their cloud services [14].

In October 2011, Trusted Cloud Initiative by Cloud Security Alliance (CSA) published a white paper to help cloud service providers to develop cloud services that meet the requirement for industry standards, secure, access controllable, interoperable, and manageable [15]. Fig. 1 shows the history of cloud computing.

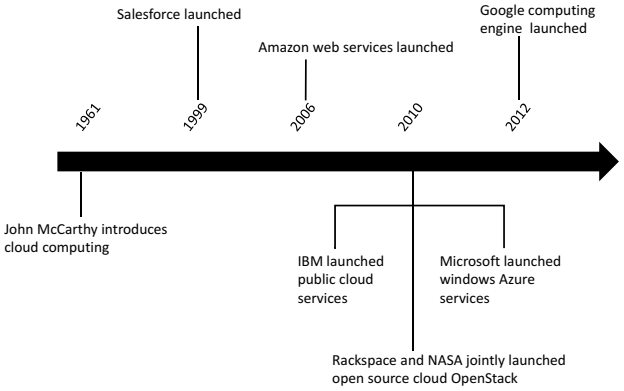

Fig. 1: History of cloud computing

III. Evolution

Cloud computing has evolved over traditional technologies. So, cloud computing can be mapped with older technologies before it has matured to the present level such as utility computing and grid computing.

- **Utility computing :** Around 1960, the processing or computing power prices were high for any purpose, so they came up with the idea of sharing computing resources. Its goal is to integrate servers, storage systems, and applications distributed around the world to share with multiple users. Sharing would allow the users to use and share the computer resources and customers using the resources can pay for the services used for the period they have used services only [4].
- **Grid computing :** is the process of solving the massive computing problems into smaller problems parts and solve these problems on simple or low-performance machines or computers to get the final result for large problems by distributing the tasks among various machines on the grid [3].
- **Cloud computing :** The concept of cloud computing is very similar to that of utility computing and grid computing. With the evolution of technologies over a couple of decades, cloud computing is possible to reach its goal in the last couple of years. In this decade cloud computing has matured a lot in terms of technology to meet all its demands.

IV. Development of Cloud Computing

In 1970, the development of cloud computing was started as a new trend, which has revolutionized the way of working and transformed traditional working environments. Following are important aspects of cloud computing development and adoption:

1) **Advantages of using Cloud Computing**
   Cloud computing simplified software development, business process, and accessing the services over the Internet. The traditional way of accessing services has changed with cloud computing. Adoption of the cloud has reduced costs, made an effective business model, and offers a great scale of flexibility for using the services. Many organizations have adopted cloud services and benefited by moving their services to the cloud. With the adoption of cloud, organizations are improving cross-platform collaboration between the developers, allowing them to do more innovations on their IT capabilities, which in turn helps the organizations to grow their business and get more revenue [1].
2) **Hybrid Cloud Computing**
   Nowadays some of the organizations started using both private and public cloud services, for various reasons such as cross-platform evaluation, to check applicability in real time scenarios across multiple platforms, and so on. Usage of public cloud service providers services even when they have private cloud services has to lead to the development of hybrid cloud computing, to have compatibility or connectivity between different cloud computing services [16].
3) **Mobile Cloud Services**

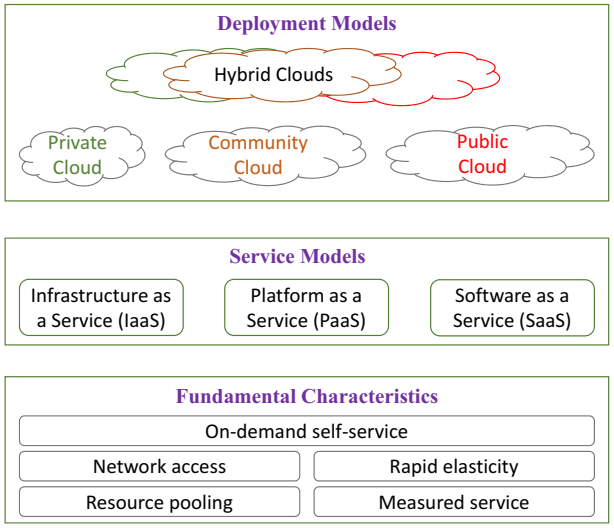

Fig. 2: Cloud computing fundamental characteristics, service models, and deployment models

As the usage of mobile devices has increased in the last decade, data generated with individuals has also increased tremendously. To gain more customers, many of the cloud service providers have started supporting mobile devices for using or accessing cloud services. Using these mobile applications or interfaces customers can store their data or access the services provided by cloud service providers [17].

4) **Cloud Security**
With the evolution of technology and cloud services many of the users are using the cloud services, but still, there is an essential problem in the cloud which needs to be addressed, such as, data security in the cloud. There are many encryption techniques and security protocols to protect the data, but with the rapid growth in technology and processing power available to attackers it becomes easy to break some of the existing encryption techniques. So, still, there is scope for new encryption techniques and security protocols for safe and secure future operations of cloud computing [18].
5) **Cloud Design**
Development of cloud services has lead to rapid adoption of the services even in traditional markets. Cloud-centric markets have advantages over conventional markets because it is convinent for younger generation to use the services. Cloud based markets attracting more new customers without physically being present in many locations with various stores in each city [19].

A. *Characteristics*

Cloud computing is a distribution of a massive computational power accessible over the Internet, rather than on the local machines. Organizations with their private data centers also work on a similar principle. Cloud computing allows organizations to move their resources where they need more processing power for their applications instead of wasting the resources that are not utilized at their full potential.

They are moving their traditional processing powers to centralized processing of data in their data centers. The shift allows computing or processing power as a commodity which can be traded over the Internet. Common characteristics of cloud computing are large scale, virtualized, low cost, geographically distributed, service oriented, resilient computing, and advanced security for services. Apart from above characteristics, cloud should also have following fundamental characteristics [2] as shown in Fig. 2:

1) **On-demand self-service :** A end-users with the need to use the computing resources at a particular time (e.g., CPU time, network storage, software, and so on) automatically and conveniently, start and stop using them without any human interference.
2) **Network access :** The computing resources delivered over the Internet and can be used by various applications from different types of devices such as laptops, desktops, and mobile devices as per the end-users requirement and availability.
3) **Resource pooling :** Cloud service providers pools (groups) all of their computing resources together to serve multiple end-users using multi-tenancy model "with different physical and virtual resources dynamically assigned and reassigned according to consumer demand" [2]. End-user should be able to use resources irrespective of their location to support location independent resource pooling.
4) **Physical transparency or Rapid elasticity :** End-users can change their resource capabilities automatically to scale up whenever they want to use more resources and release them once they are done using the services to scale down. For end-users, the resources are available for configuring with simple steps to scale up their operations and vice versa. These resources are not limited to end-users; they increase the usage of services to meet their peak requirements at any time.
5) **Pay peruse or Measured Service :** Even though all the resources are pooled and shared among multiple tenants, the end-users needs to be charged only for the cloud services they have used. This has to be taken care with a proper mechanism to measure the services used by each customer.

B. *Service Model*

Cloud computing can be segregated into the following service levels: Infrastructure as a Service, Platform as a Service, and Software as a Service as shown in Fig. 2. Fig. 3 presents the separation between service models with control of cloud service provider and customer of different underlying concepts in each model.

1) **Infrastructure as a Service (IaaS) :** Customers will get the services for a complete computing infrastructure

over the Internet. Example: Amazon EC2 [10] and S3 [20].

2) **Platform as a Service (PaaS) :** In PaaS, customers will get the platform for the development of software applications. Example: Microsoft Azure [8] and Google AppEngine [9].
3) **Software as a Service (SaaS) :** Customers will be provided with the Software over the Internet. In this model, users will not get the software; instead, they get the web-based software from the service providers to the intended work. Example: Dropbox [21] and Office365 [22].

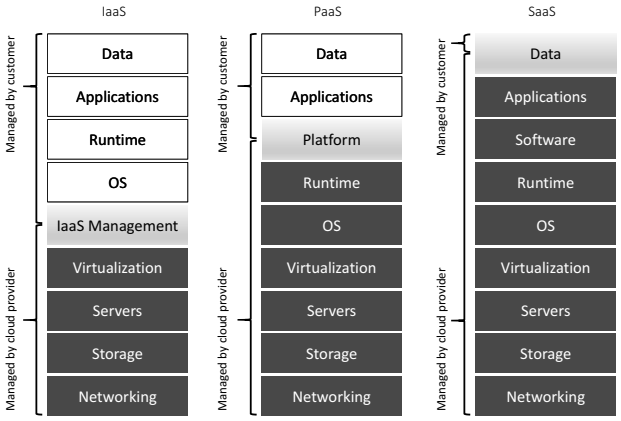

Fig. 3: Various service models in the Cloud and control of services by cloud providers and customers

C. Deployment Model

Cloud computing services are provided over the following deployment models [2] as shown in Fig. 2:

1) **Public cloud :** provides the cloud services for end-users by allowing them to access the services from the Internet. So, these cloud services are publicly accessible. The Cloud service provider provides the required infrastructure for end-users.
2) **Private cloud :** model is used within the organizations to meet the cloud requirements across various levels in the organizations. They will maintain their infrastructure to set up cloud services. This model will reduce the cost of using the cloud services for the organization in the long run with extra security as these private cloud models are deployed in their private networks behind their firewalls. Private cloud model can be accessed inside their network or by authenticating the user at their firewall.
3) **Community cloud :** model is used to deploy the cloud infrastructure that can be shared between the several organizations with similar goals. It is comparable to a private cloud but shared among some organizations.
4) **Hybrid cloud deployment model :** model is used where the customers use more than one model to meet the goals of their organizations or end-users them self.

V. Cloud Applications

Cloud computing development is directly or indirectly related to various applications using Cloud Services.

A. Software Development and Testing

Cloud computing has a lot of influences from software development and testing over the last couple of years or decades.

*1) **Software development**:* In the development of a cloud computing environment, software technology and software architecture have a lot of influence. Because of various reasons such as:

1) The applications or software developed needs to be compatible with the cloud. As the cloud platform works in combination with several aspects such as computing platform/processing power, storage capacity, and architecture used underlying deployment.
2) The application should be able to serve a large user base with huge amounts of data without any problems.
3) These services must be provided over the Internet
4) As the services are provided over the Internet, the risk of exposing confidential data is also high. So, need to have higher security for the application or services. So, that it can stand against attacks and protect private information and data of the users or organizations.
5) These services should be independent of platforms used by customers. i.e., users can use any device to access these services without any issues.

With the cloud computing environment, software development and the working environment has changed a lot compared to traditional software development. Many of these changes can be attributed to cloud-based development tools, development platform, development environment, team collaboration, and remote working of various members in the group. Cloud has been used to deploy their services online and check the services or software and evaluate them for the proper functioning of the services [23].

*2) **Software testing**:* With the adoption of a cloud computing environment for software development, software testing has some changes to cope with the new situation.

As discussed in section V-A1 with the adoption of the cloud computing environment for software development, has some changes in technology and architecture, so to meet these changes software testing also needs to be changed accordingly. Software testing should follow the traditional metrics and also adopt the changes to meet the requirements of a cloud computing environment such as dynamic capabilities, supporting a vast number of users, security, and cross-platform compatibility.

In the cloud computing environment, many of the things for software development has changed such as tools, environment, and working patterns to meet the present environment. According to these changes software testing tools, environment, and working patterns should also change to meet the cloud

environment. Testing tools need to map over the Cloud environment, unlike traditional methods. Software testing should also support collaboration, knowledge sharing, and test cases reuse in the cloud environment [24].

B. Cloud storage

Cloud computing has been added with the new extension cloud storage, used for storage of the files over the network. Cloud combines the software applications and storage space required for the proper functioning of it.

Core cloud computing environment has computing and processing power; when this system is equipped to handle or manage large amounts of data by using large storage devices, then the cloud computing environment can be treated as cloud storage system as well. So, the cloud storage is the management of the core cloud computing environment with data storage management system [25].

C. Cloud Computing and Big Data

Cloud computing and Big data are two paradigms which cannot be separated as their relation is closely connected with the other one in a technical point of view. As the term Big Data clearly explain there is a massive amount of data which can not be processed on a single machine; instead, it needs a large system with tremendous processing power. Which either can be done using the distributed processing, distributed databases, and cloud storage or in other words cloud computing needs to be used. As cloud computing can provide the required amount of resources for processing the Big Data [1].

D. Gaming

In cloud-based gaming, all the games run on the server side and console from the client side will connect to the server over the Internet and communicate, get the data related to the game in real time. On the client side, there is no need for much processing power or high-end video capable devices except basic units to communicate with the server and receive the data over the Internet. With the adoption of new technologies like 5G mobile networks will make it possible to realize the cloud-based gaming solutions into real gaming solutions. Adoption of cloud-based gaming solution will be cost effective and save a lot of money users in case they switching between several games, as some of the architectures might not support some of the games [26].

E. Internet of Things (IoT)

The term "Internet of Things" (IoT) is coined by Kevin Ashton in 1999 [27]. The IoT is nothing but the things connected to the Internet. The basic block of IoT is the Internet, with an extended network based on the elements attached to it for exchange and communicate of information. K. Rose et al. defined, "The term Internet of Things generally refers to scenarios where network connectivity and computing capability extends to objects, sensors and everyday items not normally considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention." [28].

As the adoption of IoT services increases, the demand for the data storage, processing power or computational power also increases. These capabilities can be served with a cloud computing environment, as the cloud can handle large amounts of data with the required computational power to support any of the operations to perform on the collected data from IoT devices.

VI. Cloud security

Cloud security has evolved with the adoption of Cloud Computing. The concept of cloud security is becoming more and more critical with the adoption of cloud services by more users. With many of the users around the world, if the cloud services are not protected adequately, it leaves vast amounts of customers data vulnerable to attackers from all over the worlds.

Cloud security can be achieved in several forms, protection against the Network attacks, Software attacks, Intrusion Detection, Access control, Analysis of abnormal behavior, Analysis of Virus, Analysis of Malware, Analysis of Trojans and so on. Security measures, which ensures cloud security are presented below:

1) **Password :** To secure the cloud services from simple attacks against the access controls, users are encouraged to use a unique password for accessing the cloud-based services. Customers should not use simple passwords or reuse the password which has been used on some other services over the Internet. Cloud service providers should make sure that there is no direct relation to user names and passwords stored in their database. In case there is a breach on the cloud service provider, it makes it hard for attackers to match the user names to passwords [29].
2) **Access Recovery :** Customers should use confidential details or questions, for recovering their access control to the cloud in case they forgot their password. This information can be used to recover access to the Cloud. Users should not use the information which can be gained by using social engineering or just checking some information on their social networking profiles. As most of the personal details are posted on the networking websites. Using such information, attackers can easily gain access to the Cloud without knowing the person.
3) **Encryption :** Using a good encryption technique by cloud service providers always protects the customer's data, such as Homomorphic Encryption. Usage of a homomorphic encryption technique is still not completely feasible in real time scenarios [30].
4) **Password Management :** As discussed in the first point, users should not reuse their passwords, and cloud service providers should encourage them to use strong passwords with special characters, symbol, alphabets, and numbers. It is tough for users to remember all of their user names and passwords. They need to have a proper management tool for storing their user names and

passwords to protect them from anyone getting access to them [31].

5) **Multi-factor authentication :** Multi-factor authentication adds an extra layer of security to the traditional approach to access the Cloud services instead of user name and password. To access the cloud services using multi-factor authentication, customers need to have two or more factors to access the cloud services to authenticate them as a genuine user of the Cloud. These factors can be based on anything such as knowledge (something known to the user, such as an other password), something user has (Biometric features), and something user possesses (RSA key or USB based keys or random text sent to their mobile) [32].
   Cloud services providers should support multi-factor authentication methods and encourage the customers to use the Multi-factor authentication instead of using simple authentication using user name and password. In this way, it will be easy to defend against unauthorized access to customers data even if someone has customers credentials; they wont be having access to other factors.
6) **Login Monitor :** Cloud service providers and customers need to monitor recent devices used to access cloud services. Based on that information users can identify if someone has logged in with their credentials and change their passwords in case of a suspicious login from unknown devices or locations. Cloud service providers need to improve the login statistics with proper details for all the devices connected to access the Cloud Services for all the customers [33].
7) **Personal Devices :** Customers should be careful where they are logging in to cloud to access the services. They should avoid using someone else device, as they might have key loggers (a program which saves all the keys pressed on a device, while the program is running). In those devices, if they have such applications, attackers will gain user credential for the Cloud compromising security for customers [34].
8) **Virus, Malware, and Trojans :** Customers should have good anti-virus and anti-spyware applications on their devices. If they dont have proper protection of their devices, which they use to use the cloud services might have some viruses or malware which store the user credentials and gain access to the cloud services leaving their personal and confidential details into the unauthorized persons or attackers. It would be a good habit for users to have good anti-virus and anti-spyware applications to protect their personal devices [35].

Cloud computing at present has matured a lot and solves many of the simple security aspects. Still, there are many open challenges which need to be addressed for more growth in Cloud Computing Industry.

VII. Conclusion

Cloud computing with its inception in 1961 and it's development over its predecessor utility computing and grid computing has matured a lot in the last couple of decades in terms of growth and research directions. It is evident that cloud computing is getting adopted because of its flexibility, scalability, reduced cost for using, and so on. Development of Cloud Computing can be attributed to various factors, but main attributes for its present stage can be given to software development and testing, storage capabilities, cloud gaming, Big Data, and IoT. An essential aspect of adopting the cloud can be achieved with proper security controls for the Cloud Environments and end-user behavior.

References

[1] B. Furht and A. Escalante, *Handbook of cloud computing*, vol. 3. Springer, 2010.

[2] P. Mell, T. Grance, *et al.*, "The NIST definition of cloud computing," 2011.

[3] M. L. Bote-Lorenzo, Y. A. Dimitriadis, and E. Gómez-Sánchez, "Grid characteristics and uses: a grid definition," in *Grid Computing*, pp. 291–298, Springer, 2004.

[4] M. Smith, M. Engel, T. Friese, B. Freisleben, G. A. Koenig, and W. Yurcik, "Security issues in on-demand grid and cluster computing," in *Sixth IEEE International Symposium on Cluster Computing and the Grid (CCGRID'06)*, vol. 2, pp. 14–pp, IEEE, 2006.

[5] J. O. Kephart and D. M. Chess, "The vision of autonomic computing," *Computer*, no. 1, pp. 41–50, 2003.

[6] S. Garfinkel, *Architects of the information society: 35 years of the Laboratory for Computer Science at MIT*. MIT press, 1999.

[7] Salesforce, "Salesforce crm." http://www.salesforce.com/platform. [Online; accessed 31-Jan-2019].

[8] Microsoft, "Windows azure." http://www.microsoft.com/azure. [Online; accessed 31-Jan-2019].

[9] Google, "Google app engine." http://code.google.com/appengine. [Online; accessed 31-Jan-2019].

[10] Amazon, "Amazon elastic computing cloud." http://aws.amazon.com/ec2. [Online; accessed 31-Jan-2019].

[11] N. Sultan, "Cloud computing for education: A new dawn?," *International Journal of Information Management*, vol. 30, no. 2, pp. 109–116, 2010.

[12] L. Sell, "Openstack launches as independent foundation, begins work protecting, empowering and promoting openstack." https://www.businesswire.com/news/home/20120919005997/en/OpenStack-Launches-Independent-Foundation-Begins-Work-Protecting. [Online; accessed 31-Jan-2019].

[13] Openstack, "Companies supporting the openstack foundation." https://www.openstack.org/foundation/companies/. [Online; accessed 31-Jan-2019].

[14] iDatalabs, "Companies using openstack." https://idatalabs.com/tech/products/openstack. [Online; accessed 31-Jan-2019].

[15] J. Orea *et al.*, "Quick guide to the reference architecture: Trusted cloud initiative," *Cloud Security Alliance*, 2011.

[16] A. D. JoSEP, R. KAtz, A. KonWinSKi, L. Gunho, D. PAttERSon, and A. RABKin, "A view of cloud computing," *Communications of the ACM*, vol. 53, no. 4, 2010.

[17] D. Huang *et al.*, "Mobile cloud computing," *IEEE COMSOC Multimedia Communications Technical Committee (MMTC) E-Letter*, vol. 6, no. 10, pp. 27–31, 2011.

[18] H. Takabi, J. B. Joshi, and G.-J. Ahn, "Security and privacy challenges in cloud computing environments," *IEEE Security & Privacy*, vol. 8, no. 6, pp. 24–31, 2010.

[19] A. Khajeh-Hosseini, D. Greenwood, and I. Sommerville, "Cloud migration: A case study of migrating an enterprise it system to iaas," in *2010 IEEE 3rd International Conference on cloud computing*, pp. 450–457, IEEE, 2010.

[20] Amazon, "Amazon web services." http://s3.amazonaws.com. [Online; accessed 31-Jan-2019].

[21] I. Dropbox, "Dropbox," *http://www.dropbox.com*. [Online; accessed 31-Jan-2019].

[22] Microsoft, "Office365: Documents and outlook," [Online; accessed 31-Jan-2019].

[23] P. Yara, R. Ramachandran, G. Balasubramanian, K. Muthuswamy, and D. Chandrasekar, "Global software development with cloud platforms," in *International Conference on Software Engineering Approaches for Offshore and Outsourced Development*, pp. 81–95, Springer, 2009.

[24] L. M. Riungu, O. Taipale, and K. Smolander, "Research issues for software testing in the cloud," in *2010 IEEE Second International Conference on Cloud Computing Technology and Science*, pp. 557–564, IEEE, 2010.

[25] J. Wu, L. Ping, X. Ge, Y. Wang, and J. Fu, "Cloud storage as the infrastructure of cloud computing," in *2010 International Conference on Intelligent Computing and Cognitive Informatics*, pp. 380–383, IEEE, 2010.

[26] R. Shea, J. Liu, E. C.-H. Ngai, and Y. Cui, "Cloud gaming: architecture and performance," *IEEE network*, vol. 27, no. 4, pp. 16–21, 2013.

[27] S. Madakam, R. Ramaswamy, and S. Tripathi, "Internet of things (iot): A literature review," *Journal of Computer and Communications*, vol. 3, no. 05, p. 164, 2015.

[28] K. Rose, S. Eldridge, and L. Chapin, "The internet of things: An overview," *The Internet Society (ISOC)*, pp. 1–50, 2015.

[29] A. Huth, M. Orlando, and L. Pesante, "Password security, protection, and management," *United States Computer Emergency Readiness Team*, 2012.

[30] J. Surbiryala, C. Li, and C. Rong, "A framework for improving security in cloud computing," in *2017 IEEE 2nd International Conference on Cloud Computing and Big Data Analysis (ICCCBDA)*, pp. 260–264, IEEE, 2017.

[31] S. Gaw and E. W. Felten, "Password management strategies for online accounts," in *Proceedings of the second symposium on Usable privacy and security*, pp. 44–55, ACM, 2006.

[32] W. N. Owen and E. Shoemaker, "Multi-factor authentication system," May 13 2008. US Patent 7,373,515.

[33] M. A. Plus, "Real-time monitoring of user logon actions." https://www.manageengine.com/products/active-directory-audit/monitor-user-logon-actions.html. [Online; accessed 31-Jan-2019].

[34] K. W. Miller, J. Voas, and G. F. Hurlburt, "Byod: Security and privacy considerations," *It Professional*, vol. 14, no. 5, pp. 53–55, 2012.

[35] I. Muttik and C. Barton, "Cloud security technologies," *Information security technical report*, vol. 14, no. 1, pp. 1–6, 2009.