Introduction to Cloud Resource Management

G. Sobers Smiles David, K. Ramkumar, P. Shanmugavadivu, and P. S. Eliahim Jeevaraj

1 Introduction

Data have left the building since the emergence of cloud computing. Cloud computing [3, 4] ensures the capacity to facilitate the quality computing services. With the growing of the number of users, cloud computing [5, 6] addresses the needs of the different types of domains and its requirements. Cloud consists of advancement of new business and computing technologies such as Virtualization, Grid Computing, Web Services, Cloud Computing [7, 8], and Utility Computing. Professor Leonard Kleinrock is a renowned professor of computer science at University of California, Los Angeles, USA. As a graduate student in MIT during 1960–1962, he modeled the packet networks as a mathematical model and invented the Internet technology. The development of Internet occurred in his UCLA lab (3420 Boelter Hall). His workstation became the first link of the Internet in September 1969. This host computer sent the first message to be transmitted in Internet on October 29, 1969. An idea for providing "computing as a service" was first proposed by Leonard Kleinrock. He was the chief scientist heading the Advanced Research Project Agency (ARPA) project. Kleinrock anticipated that in future computer networks will emerge as an "Utility" [1].

G. Sobers Smiles David (✉) · P. S. Eliahim Jeevaraj
Bishop Heber College, Tiruchirappalli, India
e-mail: eliahimps.cs@bhc.edu.in

K. Ramkumar
Villa College, Male, Republic of Maldives
e-mail: ramkumar.krish@villacollege.edu.mv

P. Shanmugavadivu
Gandhigram Rural Institute – Deemed to be University, Gandhigram, India

T. Choudhury et al. (eds.), *Autonomic Computing in Cloud Resource Management in Industry 4.0*, EAI/Springer Innovations in Communication and Computing,
https://doi.org/10.1007/978-3-030-71756-8_1

Since1969, Information and Communication Technology (ICT) has evolved extensively, and this vision has become a reality. The advancements in networked computing scenarios have made computing into a service model. These services could be commoditized and provided like other conventional utility delivery such as water, electricity, gas, and telephony. Time has moved on, and technology has imbibed the ideas. There are a few notable success stories to be mentioned. In 1999, Salesforce.com began providing applications to customers through a basic website. The software applications were provided to organizations through the Internet and the dream of computing as a utility started its journey [2]. Despite the success of this method, time has to pass for global acceptance.

Web services were started to be provided in 2002 by Amazon and were christened as Amazon web Services. The services included data storage, task computation, and artificial intelligence. But, not until 2006, when Elastic Compute Cloud was introduced, it became a really successful commercial offering. In 2009, Google introduced browser-oriented cloud apps called Google Apps. The year 2009 also saw other tech giants like Microsoft introducing Windows Azure and others like Oracle and HP vying for the market share with their own products [3]. And today, cloud computing [4, 5] has become mainstream. The history of the cloud is shown in Fig. 1.

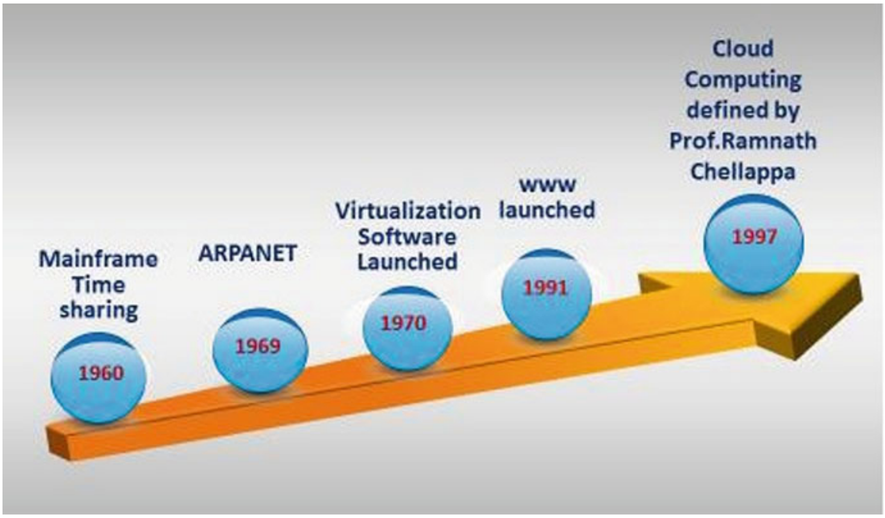

Fig. 1 History of the cloud

2 NIST's Cloud Model

The National Institute of Standards and Technology (NIST) is the standard organization of the U.S government. It defines cloud computing [6] as a computing prototype that allows pervasive, opportune, and need-based network access to a distributed collection of customizable resources such as networks, servers, storage devices, applications, and services. These resources can be rapidly acquired and freed with minimal work from administration or interaction with the service provider [7]. The NIST's Cloud model is given in Fig. 2.

NIST's cloud model consists of 5 important features. They are (1) on-demand self-service, (2) broad network access, (3) resource pooling, (4) rapid elasticity (5), and measured service [8].

The important features are elaborated follows.

- In need-based self-management of service, options are available to the user to acquire cloud computing resources on a self-service web portal.
- In broad network access, cloud computing resources can be accessed by heterogeneous devices.
- In resource pooling, the physical resources can be shared by multiple customers. This is done by segmenting the resources on a logical level.
- In rapid elasticity, on-demand resource provisioning and access is available to the user depending on the varying demands.
- In measured service, customers are billed on a pay method based on the amount of service utilized.

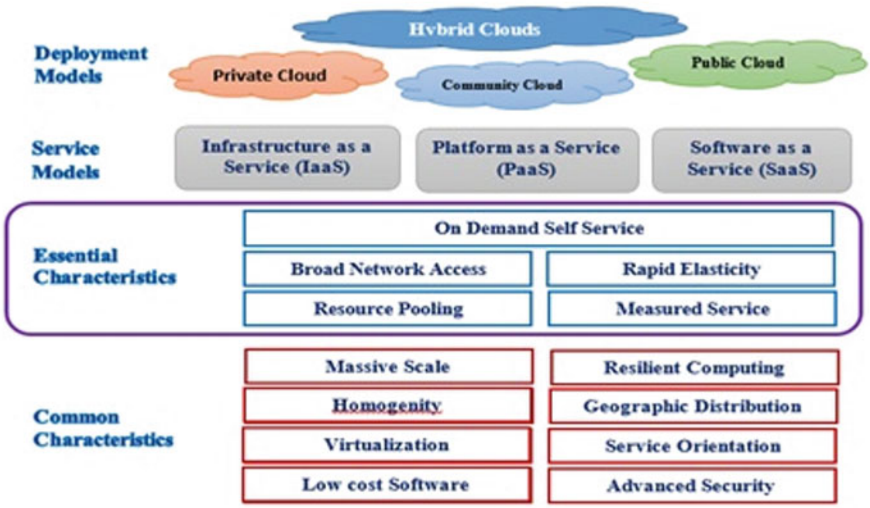

Fig. 2 NIST's cloud model

3 Benefits of the Cloud Model

Cloud computing presents enormous advantages to consumers in the form of charge or fee, faster service, and productivity. For starting a project, users need not have to invest money on resources. The need-based access to a distributed collection of resources in a self-service is offered by cloud. This service could be scaled dynamically and charged on a metered basis. There are compelling advantages using cloud computing in charges, faster delivery of services, and productivity [9]. Cloud computing is a type of computing that relies on sharing computing resources rather than having local servers or personal devices to handle applications. Cloud computing is comparable to grid computing. Grid is a type of computing where idle processing cycles of all computers in a network are coupled to solve problems that are otherwise difficult to solve for an individual machine.

In cloud computing, the word cloud is a metaphor for "the Internet". The term cloud computing refers to "Internet-based computing." Computing services like execution environment and devices, repository, and programs are delivered to an organization through the Internet. Cloud computing provides very efficient and faster computations that benefit applications to deliver personalized information, Also, Cloud provides efficient data storage and high computing power to the online applications.

To achieve this, cloud computing uses networks of enormous collection of servers. These servers run on cheaper technology such as PC. This, by employing specific connections, allows to share data handling duties. A large pool of systems that are linked together is what makes this shared IT infrastructure [10]. Containerization and virtualization techniques help maximize the computing power of the cloud. At present, there are no fully defined standards (1) for connecting the systems and (2) the software needed to make cloud computing work. Because of this scenario, many organizations define their own cloud computing technologies.

Cloud computing systems such as IBM's "Blue Cloud" technologies are based on open-source standards and software and deliver Web 2.0 capabilities [11]. Precisely, cloud computing provides Cybernation, automatic capacity adjustment, more productive development routine, better-quality demonstrability, handling the traffic fluctuations, recovery from failure, and business stability. Cloud computing could be termed as a new architype for delivering vigorous establishment of futuristic data centers by combining services of networked cybernetic machines. The true potentiality of cloud computing could be realized if the leading cloud vendors deploy cloud centers across the corners of the world. This would effectively counter failure. Data centers are slowly becoming the support for companies to maintain productivity and efficiency in their business processes [11].

4 Cloud Computing Architecture

The IT Architecture has progressed over a period time. The progress got the momentum during 1960s and the 1970s. This period witnessed costly, very big, overworking, and inflexible servers, where resources were collected, and virtualization was used expansively [12]. During 1980s and 1990s, client server technology emerged as the alternative, and the cost of computing structure and networking went down. During the 2000s, data centers emerged and were implemented in large numbers. Thus, commodity grid computing had to give way for the return of virtualization [12]. Cloud computing has taken a step further by giving need-based self-service, metered usage, fully computerized need-based resource, and amount of work management [13]. Cloud computing architecture that is responsible for distribution of cloud services contains multiple cloud constituents interacting with each other over a loosely tied mechanism such as a communique queue (Fig. 3).

Flexible allocation indicates astuteness in the use of firmly or loosely joined as applied to mechanisms such as these and others [14]. Janel Ryan et al. proposed that "In cloud computing, it is imperative to find the appropriate architecture for an application. It is the duty of organizations to recognize their application requests and their analogous cloud architecture. This would ensure the consistency and performance requests of their applications." In addition, an ideal architecture's characteristics include the following:

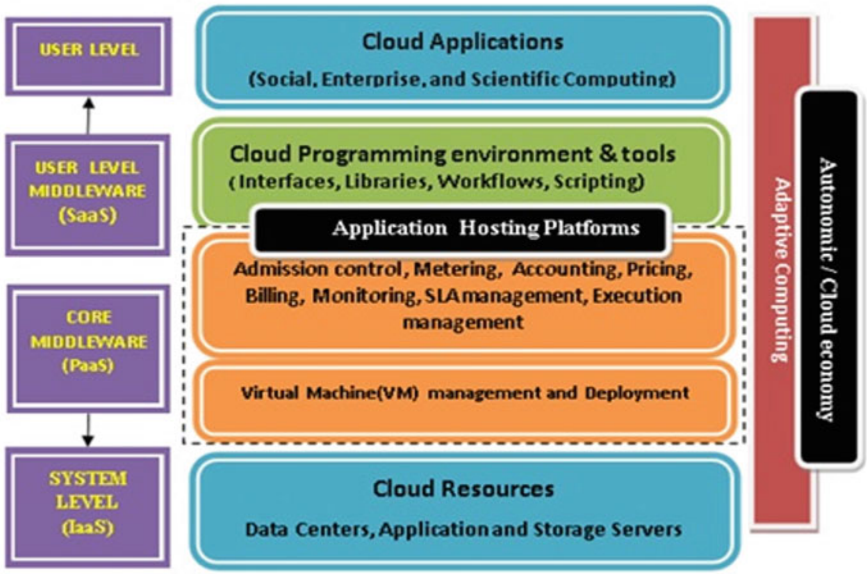

Fig. 3 Layered cloud computing architecture

- Must promote many standards within the same infrastructure with regard to resource management.
- Should aid multiple standards in the same cloud architecture and allow the customer to migrate to a newer one if they wish, with the possibility of retaining everything in the CSP network.
- Should promote use cases, multiple deployment models, and service categories.
- Must provide early detection, diagnosis, and fixing of service-related problems.
- Should help with the management of resources allotted to a user and provide reports on SLA compliance.
- Should make only the services as visible and abstract the resource allotment details.
- Must ensure security up to the Intranet level on the network.
- Should allow mobility of virtual machines within a data center.
- Must allow the users to access their resources by their actual names irrespective of the migration of resources.
- Must provide automated deployment of cloud—services to support scalable resource provisioning and configuration.

5 Cloud Resource Management

In cloud computing, resource administration includes provisioning the resource, allocating the resource, and monitoring the resource. Cloud resources include the web servers, memory, storage, network, CPU, application servers, and cybernetic machines called the virtual machines. Cybernetic machines are the processing units in cloud. The productivity of any system depends on the successful administration of resources. This is particularly significant in cloud computing systems that involve administration of enormous number of virtual and physical machines. In particular, the performance is innately reliant on the efficient management of resources [15]. Significantly, degradation in performance is caused by resource dispute by numerous applications. The varied nature of hardware resources in the cloud makes it even more challenging. Any resource administration system in cloud computing must cater to the three types of services, such as IaaS, PaaS, and SaaS. For IaaS, an adaptive resource management system (RMS) is needed to cater to the ever-changing virtual resource requests and resource constraints [16]. In short, resource management in cloud is aimed at discovering available resources, selecting the appropriate resources, and reserving the network and end system resources. This reservation mechanism ensures guaranteed service to the user's requirement. The cloud resource management phases are given in Fig. 4.

Also, the RMS should be adept at controlling complex numerous resources to performance association without any supposition of any system prototype. The RMS system must possess the ability to highly scale for supporting larger applications. For PaaS, the RMS should offer enhanced performance of the platforms on offer. It should also offer moderation for virtual resource dispute and job intervention.

Fig. 4 The cloud resource management phases

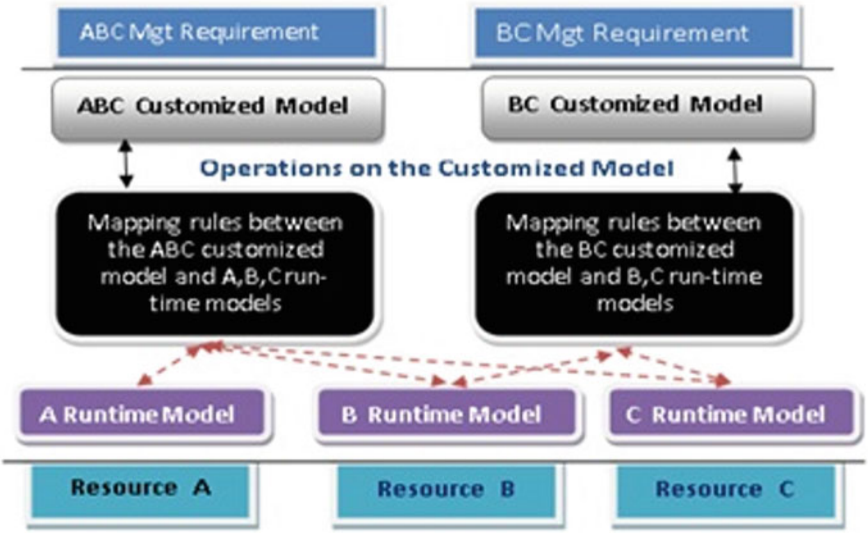

Fig. 5 The architectural model for managing cloud resources

For SaaS, the RMS must provide elasticity for varying application requests for resources and be highly flexible and offer operations for online configuration [17]. Resource allocation is the method of obtaining resources and then administering these resources by assigning them to the needed applications. The architectural model for managing resources in cloud is given in Fig. 5.

The huge bottleneck in administering cloud resources originates from the dissimilar nature of cloud applications and their resources. One of the key bottlenecks in administering resources is the administrator's familiarity with the interfaces (APIs) and their proficiency in writing programs on them [18]. In this model shown in Fig. 6, the execution time model of the resource is built, and then a synchronism model is built to avoid uncertainty. Representing rules are needed to insist on administration requests and to guarantee makeover of models [19].

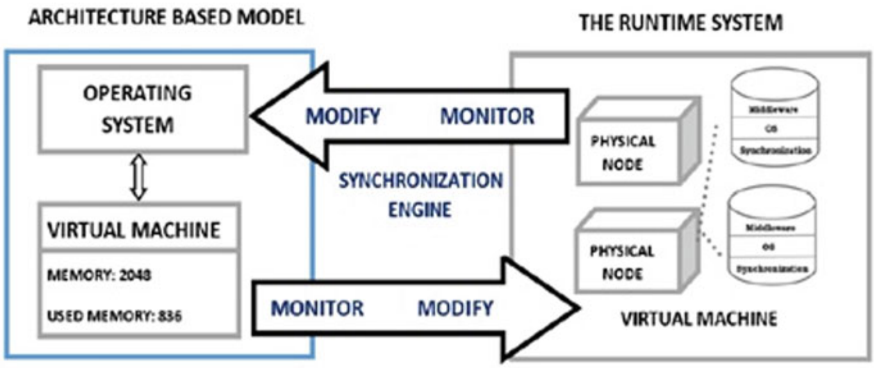

Fig. 6 The synchronization of models

6 Industry 4.0

Industry 4.0 is a strategic initiative by the German Government to transform industrial manufacturing through digitalization and latest technologies. Industry 4.0 symbolizes the fourth industrial revolution in the manufacturing field. The first revolution involved mechanization through water and vapor power. The second industrial revolution involved using current for large-scale manufacture and assembly lines. The third revolution involved computers and automations systems. The fourth industrial revolution involved enhancing the computers and automations systems with smart and autonomous systems managed by data and machine learning.

In Industry 3.0, while computers were introduced, it was the disruptive technology. It changed the entire scenario in industries involving mass production. With the emergence of Industry 4.0, the systems have become more connected and have the ability to communicate with one another. Also, the systems now have the capacity to make decisions without any human intervention. As Industry 4.0 unfolds, a rare combination of Internet of systems, mechanized systems, and Internet of things (IoT) have made the concept of Smart Factory a reality. Industry 4.0 is making the smart systems more smarter, and the production has become more efficient resulting in less wastage. The true power of Industry 4.0 lies in the network of smart machine digitally connected that are capable of acquiring new information and sharing them [20] (Fig. 7).

6.1 Industry 4.0 Applications

- *Providing insights to the manufacturer*: Smart machines collect large volumes of data through the sensors for maintenance and performance issues and analyze the data to identify any potential patterns and to acquire insights. This is not

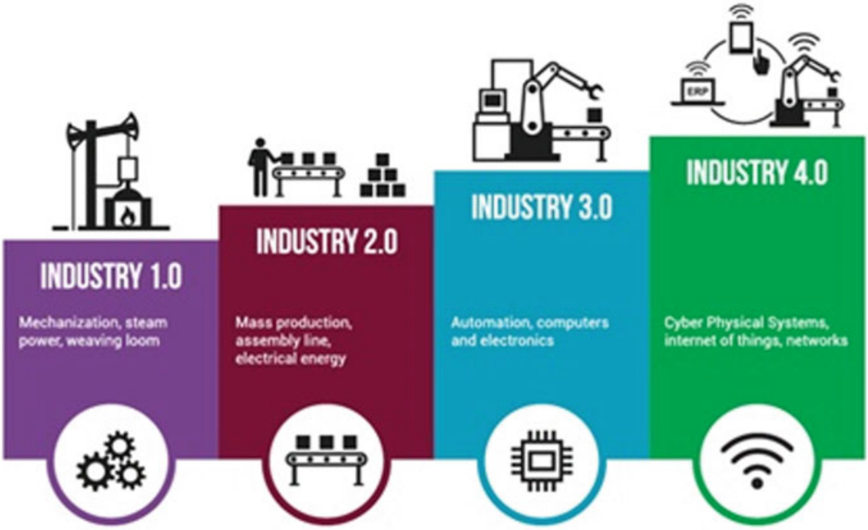

Fig. 7 Evolution of industry 4.0

possible with human workforce. Smart machines can draw the attention of the manufacturer on the issues that need immediate attention and help to optimize the operations. In the recent times, an African Gold mine employed smart machines, and the sensors identified the low level of oxygen during the leaching process. This insight helped the gold mining company to fix the problem and increase the yield by 3.7% which in turn resulted in cost saving of 20 million $ annually.

- *Connected supply chain*: Smart machines can help a connected supply chain in case of a weather delay. In such a case, smart machines can proactively adjust the manufacturing priority based on the weather scenario.
- *Autonomous vehicles*: Smart machines can manage autonomous vehicles involved in shipping yards by leveraging trucks and autonomous cranes and thereby can streamline shipping operations.
- *Robotics*: Robotics is emerging to be affordable for medium- and small-scale industries. Robots are employed in packing, loading, and readying to ship by the manufacturers. Robots bring down the cost and allow optimized use of floor space for retailers. Amazon employs robots in its warehouses and enjoys significant cost reduction in operations.
- *3D printing*: 3D printing technology has evolved from prototyping to actual production. And 3D printing technology is still evolving. With the possibility of using metal additive manufacturing, 3D printing has opened a floodgate of opportunities for production.
- *Internet of things (IoT)*: The emergence of Internet of Things has brought in a sea of changes in the way internal operations are done. Equipment and operations could be optimized through cloud environment. This also opens up the possibility

of sharing the insights with organizations that use the same equipment and gives smaller companies a chance to access the technology insight [21].

7 Significance of Cloud Computing in Industry 4.0

The role played by cloud computing for continuing the development of the Fourth Industrial Revolution, Industry 4.0, is very crucial. As with its characteristic, Cloud technology assists to collect resources and integrate information for businesses. It also offers an opportunity for open-source group effort that helps to expedite and refine research. The first phase of the fourth industrial revolution is happening in Automotive and manufacturing industries. Distributed cloud is one of the key technologies to harness the growth in Industry 4.0. Cloud computing has allowed businesses to voluntarily change with the evolving times without dropping data, made possible with the integration of artificial intelligence and automation into industry, cloud computing provides unprecedented network, storage, and computing abilities. Compute services enable the platforms capable of merging Internet of Things, robotics, and automation, which contribute to innovation [22].

The IT enterprise is about to be reshaped due to a seismic shift. Due to the introduction of key trends like Artificial Intelligence and Internet of Things, applications and data are more and more being extended across multiple data centers—some on onsite and some in multiple clouds—and edge sites hitherto encapsulated in their supporting infrastructure. A recently held Gartner study reveals that, by 2022, half of the present enterprise-generated data will move to a single centralized cloud. The study has also forecasted that by 2025 this number will rise to 75–90% [23]. This scenario will lead to two distinct and separate phenomena: (1) the clouding of the edge and (2) the rise in proper multicloud [22]. And these developments point to the rise in the distributed cloud as shown in Fig. 8.

Distributed cloud is an application of Cloud Computing used to interconnect data and applications that can be provided from various geographical locations. In distributed computing, the data and applications are shared among multiple systems located in different geographical locations. This enables cloud to speed up communication for global services and more responsive communication for particular region [23].

7.1 Types of Distributed Cloud

There are two types. (1) Public resource computing (2) volunteer cloud

- Public-resource computing:

  This is a subclass of traditional cloud computing and more related to distributed computing. This is also referred as Global Computing and peer-to-peer

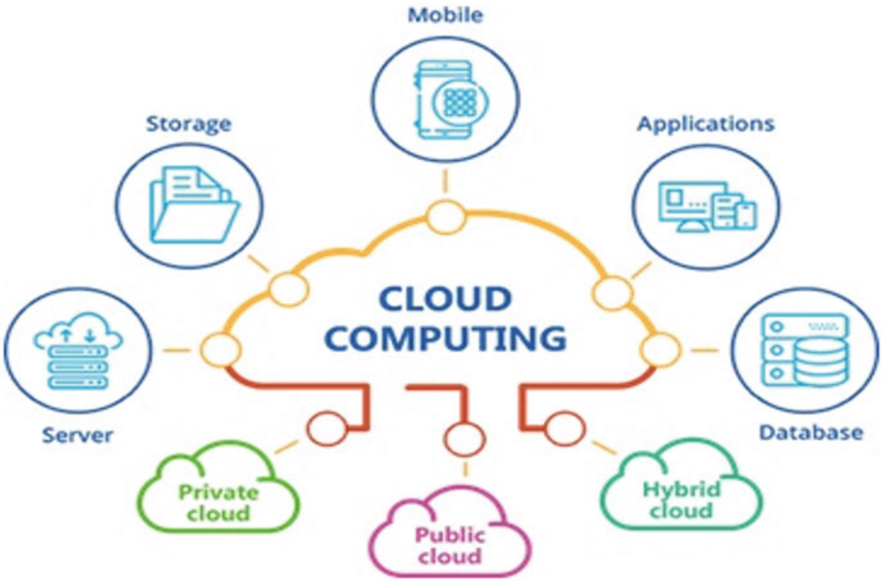

Fig. 8 Distributed cloud computing scenario

computing. This type of computing is employed in scientific supercomputing. The number of systems with Internet connectivity is growing almost every second. The combined computing power of these systems is enormous, almost equivalent to many data centers [24].

- Volunteer cloud:

  This is a combination of cloud computing and public-resource computing. Here, the cloud computing structure is constructed with willing resources. This type of cloud is also referred as Ad hoc clouds.

7.2 *Benefits of Distributed Computing*

- Helps to reduce costs by offering repetition, dependability, and geo-replication.
- Easy to respond in case of failures by employing remote replicas that can instantly reset.
- Reduced wide-area traffic by using the distributed cloud resources.
- Allows parallel processing of tasks by breaking a complex problem and data into segments and employing multiple systems to work on it.

7.3 Challenges With Distributed Computing

- Very high deployment cost involved with processing overhead due to additional computation and exchange.
- Requires more maintenance and security [25, 26] as users also have to deal with replicated data provided from multiple locations.
- Difficult to maintain, deploy, and troubleshoot hardware and software due to the volume of data and size of the applications associated.

8 Use Cases for Cloud Computing in Industry 4.0

The cloud [1] is a fantastic, federated tool that is altering the approach how data are stored and managed. Companies are now more open to amalgamating and partaking information rather than secreting it from competitors. Cloud [2] has enabled to open up channels of information exchange which will be of value to the whole industry. This also has resulted in faster and more refined results.

The mobile networks, 4G which is in use today, and the emerging 5G technology, are designed to support higher frequency range and lower response time communication. This is available on the broadcasting interface for both downlink (DL) and uplink (UL) data. This makes it an ideal scenario for Industry 4.0. Distributed cloud [3] makes use of these features, enabling a widespread runtime environment for applications. This ensures communication with short latency, high reliability, performance, and data locality [27].

The complexity of the infrastructure is hidden by the distributed cloud. Simultaneously, the elasticity of cloud computing [4] is also maintained. Also, the application components are kept in an optimal location. This enables to avail key characteristics of distributed cloud. Many manufacturing industries and the automotive sector already have use cases, and they are most likely the first ones to adopt distributed cloud technology.

8.1 The Next-Generation Services for Automotive Sector

The next-generation services for automotive sector aims to transform driving, ease the movement of vehicles, manage energy usage competently, and emit low. All this could be possible only when the automobiles support mobile communication in their vehicles. With the addition of mobile communications, automotive service could include intelligent and automated driving, use of sophisticated maps that includes real-time data, and innovative driving support using cloud [4–6]. The driving assistance using cloud could make use of cloud-based analytics of uplink video streams. These processes involve large chunks of data to be stored in cloud and transmitted between vehicles when the vehicle is active and on the move with actual time features within a stipulated time.

The real-time use case for safety in automotive industry is vehicle to everything/co-operative Intelligent Transport System (V2X/C-ITS), where short latency is one of the main requirements. The new class of cloud-based services by automotive industry is possible only when large volumes of real-time data with real-time characteristics are able to be transmitted between mobile vehicles. This puts a huge demand on the network capacity. Also, actual time data require to be transmitted not beyond a stipulated time frame of 30 min/day. These data with changing geographical collection of vehicles employ different rules and network technologies. By the year 2025, the global estimation for the number of connected vehicles is 700 million. And the data volume estimation is 100 petabytes/month. But, at Ericcson, the estimation is comparatively low at 10 Pb/month. At the same time, Gartner expects the volume to be 1 TB/month /vehicle [28]. The Automotive Edge Computing Consortium (AECC) white paper states that the effective handling of large volumes of data is not supported by the present computing and network architectures. The white paper has also suggested remedial measures. Of these, three recommendations stand out: (1) filtering the data while it is allowed in the cloud; (2) employing topology-aware computing and storage services otherwise called as Global Automotive Distributed Edge Cloud; and (3) upgrading the mobile network capacity, availability, and coverage to cater to the growing demand.

8.2 Localized Network With Distributed Computing

In order to streamline traffic and data-processing problems in the existing ubiquitous systems, Ericcson developed the concept of localized network with distributed computing services. Here, the connectivity of vehicles is taken care by the respective localized networks with network coverage. All the processing of data associated with a vehicle is done locally, thereby reducing the amount of data traffic. This enables faster communication for the vehicles.

There are three key components in this concept: (1) a localized network; (2) edge computing; (3) and data exposure. A localized network is a restricted network that consists of minimal connected vehicles in a particular region. In this network, the level of movement between the means of transportation and the clouds is significantly reduced. Edge computing represents distributed computational resources in the range of a localized network. This results in less computation and less processing time for data exchange to connected vehicles. Data exposure combines the restricted network and the distributed processing. It also secures integration of the locally produced data. Data can be rapidly processed by contracting related data down to a particular area, thereby enabling the network to integrate the information. Further, the connected vehicles could be notified in real time. Extreme care is needed to keep the size of the data as minimum during transmission of data [29].

8.3 5G Technology and Augmented Reality

Recent research indicates that 5G technology will empower automotive industry with wide deployment of interactive media applications. Also, Machine learning and augmented reality will be the two main technologies that will be extensively used in the digitization of industries. It is expected that the future workers will use more of eye-tracking smart glasses and tactual gloves than any physical equipment. In such a case, human-to-machine interaction will require heavy compute resources, high network bandwidth, and low latency network. The limitations involved with light waves used in optic fibers rule out the possibility of running the complete application in large central databases [30].

The components of the application can be executed in three possible ways. (1) On the device itself, (2) in the edge server, and (3) in the central cloud. Here, the device could be offloaded with minimal latency by setting up application constituents at the network edge. In order to determine the 3D position of objects, more synchronization is needed for numerous actual time camera feeds. This mechanism is optimized by edge compute. Further, more services are also provided on the edge site in the form of advanced cloud software as a service.

8.4 Distributed Cloud Solution by Ericcson

Developers and researchers at Ericcson have designed a disseminated cloud solution that could provide all the necessary competencies supporting the usage scenarios of Industry 4.0, including localized networks and private networks. This distributed cloud solution satisfies all the security requirements needed for a smart factory. Further, this cloud solution provides edge computing and makes sure all the end-to-end network requirements are met. In addition, this cloud solution also provides orchestration, management, and exposure for the cloud and network resources together [31].

The distributed cloud is defined as a distributed execution environment spread across multiple sites situated at different geographical locations and managed as a single entity.

- The cloud infrastructure resources are abstracted, and the complexity involved in allocating the resources is hidden to the application and the user.
- The cloud solution is based on the technologies, such as 3GPP edge computing technology, network functions virtualization, and software-defined networking.
- The use of the abovementioned three technologies enables open access for applications.
- This solution also supports automated deployment in heterogeneous clouds.

9 Conclusion

Global standards and Common Architecture for Industry 4.0 are still in its nascent stages. An ideal solution would be coming together of industries and vendors creating an ecosystem and formulating the requirements, use cases, working methods, common reference implementation mechanisms, and standards to be followed. The world is looking forward to ecosystems such as Automotive Edge Computing Consortium (AECC), The 5G Alliance Connected Industries and Automation (5G-ACIA), Industrial Internet of Things (IIoT), and Industry 4.0 to join and formulate the mechanisms. Industry 4.0 has truly become the game changer. With the advancements in artificial intelligence and machine learning, the scenario can only get better and better. The emergence of 5G technology has opened the doors for automated transport and vehicles. Days are not far when everything around the human beings will move toward automation.

References

1. Alex, Y. A. G. (2017). Comparison of resource optimization algorithms in cloud computing. *International Journal of Pure and Applied Mathematics*, 847–854.
2. An architectural blueprint for autonomic computing. (2005). *Autonomic computing white paper*. Third Edition: IBM Press.
3. Vashistha, A., Kumar, S., Verma, P., Porwal, R. (2018). A self-adaptive view on resource management in cloud data center. IEEE Computer Society.
4. Singh, B. K., Alemu, D. P. S. M., & Adane, A. (2020). Cloud-based outsourcing framework for efficient IT project management practices. *(IJACSA) International Journal of Advanced Computer Science and Applications, 11*(9), 114–152.
5. Tomar, R., Khanna, A., Bansal, A., Fore, V. (2018). An architectural view towards autonomic cloud computing. Data engineering and intelligent computing (pp. 573–582).
6. Yadav, A. K., Tomar, R., Kumar, D., Gupta, H. (2012). Security and privacy concerns in cloud computing. *Computer Science and Software Engineering*.
7. Lee, Y. C., & Zomaya, A. Y. (2012). Energy efficient utilization of resources in cloud computing systems. *The Journal of Supercomputing, 60*(2), 268–280.
8. Biography of Leonard Kleinrock. *IEEE Computer Society* (2019).
9. Sheshasaayee, A., & Megala, R. (2017). A study on resource provisioning approaches in autonomic cloud computing. In *International conference on I-SMAC (IoT in social, mobile, analytics and cloud) (I-SMAC 2017)* (pp. 141–147). IEEE Publications.
10. Mell, P., Grance, T. (2011). The NIST definition of cloud computing. *Computer security*. NIST Special Publication 800–145.
11. Sukhpal Singh Gill, Peter Garraghan, Vlado Stankovski, Giuliano Casale, Ruppa K. Thulasiram , Soumya K. Ghosh, Ramamohanarao, K., Buyya, R. (2019). Holistic resource management for sustainable and reliable cloud computing: An innovative solution to global challenge. *The Journal of Systems and Software, Elsevier Publications*. 102–127.
12. Dehraj, P., & Sharma, A. (2021). A review on architecture and models for autonomic software systems. *The Journal of Supercomputing, Springer Nature, 77*, 388–417.
13. Pompili, D., Hajisami, A., & Tran, T. X. (2016). Elastic resource utilization framework for high capacity and energy efficiency in cloud RAN. *IEEE Communications Magazine, 54*(1), 26–32.

14. Felter, W., Ferreira, A., Rajamony, R., Rubio, J. (2015). An updated performance comparison of virtual machines and linux container. 2015 IEEE International Symposium on in performance analysis of systems and software, (ISPASS) (pp. 171–172).
15. Beloglazov, A., & Buyya, R. (2013). Managing overloaded hosts for dynamic consolidation of virtual machines in cloud data centers under quality of service constraints. *IEEE Transactions on Parallel and Distributed Systems, 24*(7), 1366–1379.
16. Coutinho, E. F., Gomes, D. G., & Neuman de Souza, J. (2015). An autonomic computing-based architecture for cloud computing elasticity. In network operations and management symposium (LANOMS) (pp. 111–112).
17. Tesfatsion, S. K., Wadbro, E., & Tordsson, J. (2018). PerfGreen: Performance and energy aware resource provisioning for heterogeneous cloud. IEEE international conference on autonomic computing, *IEEE Computer Society*.
18. Vieira, K., Koch, F. L., Sobral, J. B. M., Westphall, C. B., de Souza Leão, J. L. (2019). Autonomic intrusion detection and response using big data. *IEEE Systems*. https://doi.org/10.1109/JSYST.2019.2945555.
19. Vuksanović, D., Ugarak, J., Korčok, D. (2016). Industry 4.0: The future concepts and new visions of factory of the future development. International scientific conference on ICT and E-business related research. *Advanced Engineering Systems* (pp. 293–298).
20. Rojko, A. (2017). Industry 4.0 concept: Background and overview. *International Journal of Interactive Mobile Technologies (iJIM).*
21. Alcácer, V., & Cruz-Machado, V. (2019). Scanning the industry 4.0: A literature review on Technologies for Manufacturing Systems. *Engineering Science and Technology, 22*, 899–919.
22. Zhou, K., Liu, T., Zhou, L. (2015). Industry 4.0: Towards future industrial opportunities and challenges. 12th international conference on fuzzy systems and knowledge discovery (FSKD) 2015 (pp. 2147–2152).
23. Boberg, C., Svensson, M., Kovács, B. (2018). Distributed cloud – A key enabler of automotive and industry 4.0 use cases. *Charting the Future of Innovation, Ericcson Technology Review, No.11–2018.*
24. Khan, A., Turowski, K. (2016). A perspective on industry 4.0: From challenges to opportunities in production systems. In proceedings of the international conference on internet of things and big data (IoTBD 2016), scitepress (pp. 441–448).
25. Nahar, K., & Chakraborty, P. (2020). Improved approach of rail fence for enhancing security. *International Journal of Innovative Technology and Exploring Engineering, 9*(9), 583–585. https://doi.org/10.35940/ijitee.i7637.079920.
26. Nahar, K., & Chakraborty, P. (2020). A modified version of Vigenere cipher using 95 × 95 table. *International Journal of Engineering and Advanced Technology (IJEAT), 9*(5), 1144–1148. https://doi.org/10.35940/ijeat.E9941.069520.
27. Sharma, M., Kumar, R., & Jain, A. (2019). Implementation of various load-balancing approaches for cloud computing using CloudSim. *Journal of Computational and Theoretical Nanoscience, 16*(9), 3974–3980.
28. Jain, A., & Kumar, R. (2014). A taxonomy of cloud computing. *International Journal of Scientific and Research Publications, 4*(7), 1–5.
29. Compastié, M., Badonnel, R., Festor, O., He, R., & Kassi-Lahlou, M. (2016). A software-defined security strategy for supporting autonomic security enforcement in distributed cloud. IEEE 8th international conference on cloud computing technology and science, IEEE Computer Society.
30. John, W., Sargor, C., Szabo, R., Awan, A. J., Padala, C., Drake, E., Julien, M., Opsenica, M. (2020). The future of cloud computing - highly distributed with heterogeneous hardware. *Ericcson Technology Review*.
31. Eriksson, A. C., Forsman, M., Ronkainen, H., Willars, P., Östberg, C. (2020). 5G new radio RAN & transport – Choices that minimize CTO. *Ericcson Technology Review*.