LEVERAGING THE SCALABILITY: A DISTRIBUTED CLOUD FOR TOMORROW'S INTERNET OF AUTONOMOUS THINGS

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Abstract: *In a cloud computing environment, the dynamic resource distribution is especially important for accomplishment of customer demands in a fast and secure manner. A distributed cloud uses fog and edge computing in its infrastructure to reduce the latencies by offering computation and data storage closer to devices.*
This paper presents the concept of distributed cloud computing and its base components and propose a three-layered architecture model. The study also discusses several platforms which implement the concept in different application areas, such as education, the automotive sector, manufacturing industry and transport.

Keywords: Distributed Cloud Computing, Internet-of-Things, Business model, Smart manufacturing.

JEL Classification Codes: C63, C88, M15, L60.

1. INTRODUCTION

Among the top 10 strategic technology trends for 2020, Gartner included empowered edge, distributed cloud and autonomous things, as mentioned the yearly Gartner Special Report (Panetta, 2019).

By analysing the significance and functions of each of these three trends, it is obvious that they converge towards the same purpose, namely the development of the Internet of Things.

Edge Computing is a distributed IT architecture whereby data collection and processing is based on the capabilities of computing resources placed closer to the sources and consumers of this information, with the main advantage of increasing network performance.

Gartner researchers consider that the devices at the edge of the network will be empowered as "smart spaces" and will offer "many key applications and services" to end users.

Distributed Cloud represents a major evolution in the cloud computing domain, which makes the transition from a centralized model to one offering decentralized services, delivered by an access point, that could be an end-user or edge device.

According to the Gartner Report, "Distributed cloud represents the distribution of public services of the cloud in different locations, whilst the public provider assumes responsibility for the operation, administration, updates and evolution of the services" (Panetta, 2019).

Autonomous things were the first technological trend on 2019 Gartner's list and have also an important place on 2020 list.

Autonomous things (AuT) or the Internet of autonomous things (IoAT) are physical devices that use AI (Artificial Intelligence) to automate standalone or collaborative functions with other smart things or with humans. These new IoAT devices are objects that can work independently and can self-organize to deal with situations they were never programmed to solve.

According to the aforementioned Gartner Report, “As technological capacity improves, regulations allow, and social acceptance grows, autonomous things will be increasingly deployed in uncontrolled public spaces” (Panetta, 2019).

These three trends have a common goal, namely the idea of "smart spaces” for humans, consisting in intelligent technologies that will influence people (customers, employees) and their places for working and for living.

Distributed cloud applications include Internet of Things (IoT), Industry 4.0, Machine Learning, Artificial Intelligence (AI), Independent Driving, and others.

The paper contains four sections: Literature Review, to provide an overview of the actual stage of Cloud computing and its siblings, Methodology for defining several models of Distributed Cloud and choosing the simplest and most feasible, DCC Applications and Results, to analyse the approaches on IT market and their benefits and Conclusions, to mention several final remarks and future ideas related to this new trend.

2. LITERATURE REVIEW

This section is designed to provide a brief overview of the Cloud Computing technology and the advantages of using it in IoT development.

Cloud computing is a technology that “removes the limitations of local hardware and software resources, by providing access to a common pool of infrastructure services (processing, storage, sharing of network resources, etc.) and the specific applications in a secure environment” (Banica et al., 2017).

Cloud computing is a competitive environment for many powerful corporations, which developed a wide range of cloud-based solutions, taken into account aspects concerning the storage capacity, the security of hosted data, the services provided, but also the subscription cost (Banica & Radulescu, 2015).

Cloud computing is focused on the massive, centralized datacentres model, replicated by instances on a wide scale, based on powerful hardware resources. This model has also several drawbacks, such as: data security risks, data loss challenge, system unavailability or failure of an area leading to the impossibility of accessing data in a timely manner, network latency etc.

To solve the problems of network congestion and delays in responding to requests from IoT devices or end-users, a new technology has emerged, called Fog/Edge computing.

Fog/Edge computing is a way to decentralize operations from Cloud, whereby data storage and processing occurs closer to the location of smart things (Zhang, 2016).

This method has the main advantage that most applications and services no longer run in Cloud clusters, but are distributed in nodes placed closer to the IoT devices, which have their own storage and service processing capacity required by the connected devices.

Distributed Cloud Computing (DCC) refers to storage, computation and networking resources placed in a micro-cloud located outside the centralized Cloud, processes data in real-time and is directly accessible to the end-user. (Boyd, 2018)

On the other hand, such a micro-cloud cooperates and controls a number of Fog/Edge nodes, which can provide storage and processing capacity of services through distributed resources.

Khethavath et al. introduces another interesting idea, starting from the advantages of distributed computing over centralized architectures, namely proposing a competition between those who provide resources to the users (Khethavath et al., 2017). They evaluated multiple schemes for resource discovery and allocation, and finally they proposed a simultaneous Auction mechanism to select a winner (or a set of winners) after receiving the offers. We must also mention that one of the important selection criteria is the price for providing a resource.

Distributed Cloud opens another perspective in Cloud computing, meaning that applications, tools, security, management and other services physically move from a centralized model to one where services are distributed and delivered at the access point.

In the following sections we will propose several models of DCC implementation and we will analyse some software products, the advantages and disadvantages of each of them from the IoT development point of view.

3. METHODOLOGY

Distributed Cloud is a version of Cloud computing that not only offers centralized resources, but also provides decentralized cloud services, being placed closer the users who request them.

The new paradigm is based on the terms **Distributed** and **Cloud** computing, and from the simple interpretation of their association we can derive the meaning, as a complex system based on distributed storage and computation in the Cloud environment.

Thus, a request from an IoT device can be served by distributing component tasks amongst different micro-clouds, each of them having certain capabilities: storage, computing, micro-services, etc.

Though the Distributed Cloud also involves the use of a heterogeneous environment, that need to be coordinated to obtain compatibility between services, networks and individual components and a better performance than a centralized solution.

3.1 Cloud computing concept and models

National Institute of Standards and Technology (NIST) defines Cloud Computing as: „a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell and Grance, 2011).

From this definition one can infer the main components of the concept (Banica et al., 2014):

- the features of cloud computing: resource pooling, broad network access, on-demand self-service;
- the cloud service models (software, platform and infrastructure),
- the deployment models (private, community, public etc) that provide direction to deliver cloud services.

NIST defines three fundamental models for Cloud computing services: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). In addition to the three models, on the IT market a fourth model of cloud services: Business Process as a Service (BPaaS) has emerged (Sreekanth I., 2010).

The services provided by each model are (Banica et al., 2014):

- Infrastructure as a Service (IaaS) is the base layer of the cloud, where hardware resources are dynamically allocated and offered to the user on a pay-per-use model;
- Platform as a Service (PaaS) involves a provider-owned tough customizable ecosystem with all the necessary components hosted and managed remotely, offering the customer the perfect environment to deploy enterprise applications without worrying about the underlaying platform; the runtime components are already installed and updated automatically;
- Software as a Service (SaaS) represents the most sophisticated cloud model, as it involves a full stack of server components that are completely managed by the provider, including the applications that is directly accessed by the client through dedicated programs; this model completely relieves the client from the burden of managing their software;

- Business Process as a Service (BPaaS) tries to achieve more than client applications, as it involves additional business functions, such as payment processing, human resources management (Harding et al., 2011).

3.2 From Cloud computing towards Distributed Cloud Computing

Distributed Cloud Computing (DCC) comprises hardware and software components that belong to multiple Micro-Clouds and are integrated into a complex system.

This new technology includes (Craven, 2020):

- distributed computing systems
- distributed storage systems
- serving the requests received from devices/end-user through micro-services placed at the Fog/Edge computing level:
- the capability of adding/modifying services without affecting the other components
- decomposing complex programs into tasks that are distributed between different machines for parallel processing
- the complexity and details of the corresponding infrastructure are transparent for the users which can easily access the services through a graphical interface.

A distributed cloud uses fog computing and edge in its infrastructure to improve the transfer rate and reduce network congestion through storing data and performing tasks closer to devices.

From the Fog/Edge level, the traffic is still transmitted to a cloud datacentre - distributed or centralized, which has more power and storage capacity, for analytical processing with Big Data tools, but no longer interacting directly and with various customers (Craven, 2020).

As mentioned earlier, Fog/Edge computing is a Cloud computing technology where data is processed as close as possible to the place of its generation, in order to resolve high-traffic critical points and offer low network latency. Fog/Edge also offers advantages in situations when data transmission requires security and confidentiality, and their encryption is not enough, and public transport networks are unreliable. This technology integrates very well into the new Distributed Cloud Computing concept, considering that Fog/ Edge resources function as micro-Cloud workstations, with local storage and computing resources, connected to the macro-Cloud data centers for Big Data storage and complex analysis.

Figure 1 shows a Distributed Cloud Computing model, a three-layer architecture.

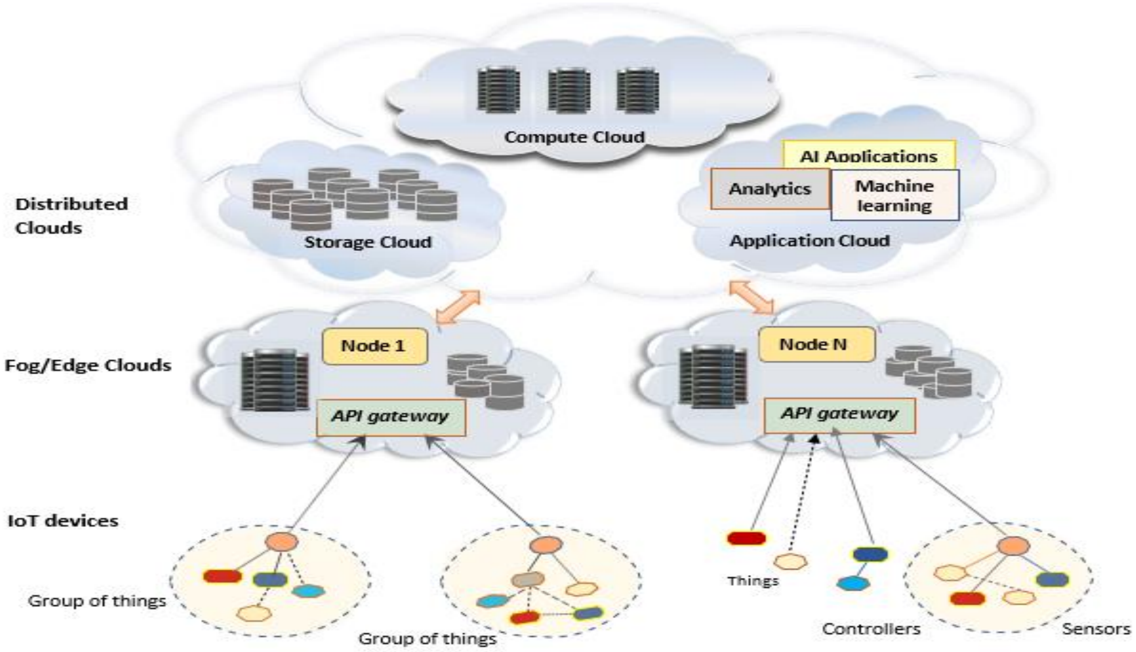

Figure 1. Distributed Cloud Computing Model

The key benefit of using cloud services is the ability to provide users with on-demand computing and storage features and minimize their own IT infrastructure.

With distributed cloud computing, the services are requested by the user through a call-centre, which allocates them in a pool of resources in a transparent manner for the applicants.

But, a DCC model requires high-speed data interconnections between these geographically dispersed call-centres.

Furthermore, cloud providers could integrate with these scattered cloud datacentres, using their own technology, and providing all services in a way that's transparent to the users (Stackpath, 2020).

4. DISTRIBUTED CLOUD COMPUTING EXPERIMENTATION WITH SOFTWARE PLATFORMS

4.1 Distributed Cloud platform

The major Cloud providers, such as Amazon Web Services (AWS), Microsoft Azure, Oracle Cloud and Google Cloud Platform already have a global network of datacentres and have edge devices available or PoPs, but they are running their services primarily in centralized manner (Craven, 2020)

The services are available to ordinary customers, small and large businesses via Cloud platforms, which are generally licensed and highly secure software.

An example can be the StackPath software, that allows the connection to and execution of tasks on the edge nodes through Points of Presence (PoP) placed anywhere and that offer different processing power and number of instances.

Another example is Volterra, which provides a SaaS-based, distributed cloud platform to deploy, connect, secure and operate apps and data across multiple clouds and edge sites (Volterra, 2020).

Volterra includes three SaaS-based components: VoltStack, VoltMesh and Volterra Console (Figure 2):

1) VoltStack is able to manage scalable software across many locations in cloud or edge;

2) VoltMesh is focused on high-end services involving mesh infrastructures across cloud environments;
3) Volterra Console is the Control panel of the whole infrastructure, offering a single point of contact that facilitates the management of software (Volterra, 2020).

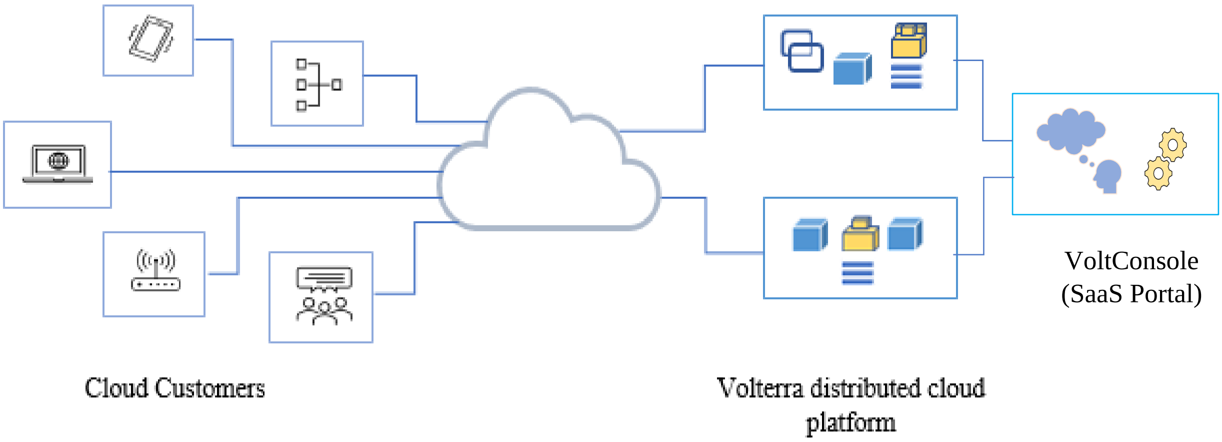

Figure 2. Volterra platform

Souce: https://www.volterra.io/products/

Distributed cloud will expand as the need for edge computing will increase to support the IoT devices. As fog/edge computing becomes more commonplace, cloud services will also decentralize.

4.2 Distributed Cloud: advantages and areas of application

The main advantage of DCC is the placement of the services closer to users with better availability and shorter response time.

Industry 4.0 applications benefit from these advantages in order to reduce production downtime and increase operational security.

Other advantages are (Craven, 2020):

- the distributed cloud infrastructure is transparent to the users and works regardless of the user's location
- represents the most suitable model for the continuous deployment of micro-services, convenient to geographically-spread clients
- distributed cloud model is suitable for real-time applications.

Public cloud solutions based on powerful datacentres, even with replication strategies in place, have the disadvantage that the failure of an area can cause the failure of all customers assigned or their temporary reallocation to replicas.

Therefore, the distributed cloud model is an appealing alternative, as it is based on micro datacentres interconnected by high bandwidth links and managed unitarily.
This model is the most suitable solution for *public clouds run by mobile network operators*, model which offers a platform where applications can be easily deployed and managed, platform that has the advantage of a tighter coupling with the radio access network (RAN) (Coady et al, 2015)

Other distributed cloud application areas are the following:

- Educational domain: students can test their programs by running them on remote systems; also, they can share their experiences concerning the courses and use educational games (Stackpath, 2020)

- This new concept is recommended also for Content Delivery Networks (CDNs), because decentralization ensures the correct transmission of complex content, such as high-quality videos, regardless of the client location.
- Smart transport: collecting traffic data and engine parameters from the sensors on the vehicles through a distributed cloud, which also analyses the information received; then data is used to compute the optimal routes through a local cloud and identify vehicles due for maintenance (Stackpath, 2020)
- The automotive sector and many manufacturing industries are also interested in distributed cloud technology.

Cloud-based engineering solutions in the manufacturing sector eliminate barriers between small and medium-sized companies and large companies, where data is an increasingly important asset in the digital-age business. This means lower costs, better profitability and shorter time to market for advanced technologies.

The digitalization of the workplace based on the distributed cloud is suitable in organizations where the design, manufacture, or production planning frequently operate as independent "silos". If this data could be aggregated and extended to allow the total simulation of a real production process, a new perspective on operations is reached, achieving the level of Digital Twin (DT).

The entire manufacturing process can be simulated in the digital version of a factory, as a DT in a distributed cloud environment. Each component of the Digital Twin model can belong to a different micro-cloud, being transparent for the enterprise.

Data provided from component sensors via micro-clouds will determine some operations, will continuously update the twin virtual system in parallel with the physical system, thus keeping the digital model on par with real world data, and ensure an active feedback from the virtual model. This workflow leads to a highly-optimized machine operation, increases the ability to forecast issues and streamlines the maintenance of components.

The Digital Twin based Distributed Cloud concept can be successfully extended to other areas adjacent to product manufacturing, such as: optimization of supply chains through the digital modelling of product distribution, storage and distribution networks, customer relationship management, in order to better track and predict customer needs (Banica & Stefan, 2019).

5. CONCLUSIONS

Nowadays, most businesses rely heavily on their own infrastructure or IaaS cloud services. The evolution of IT is fast moving towards artificial intelligence areas (machine learning, robotics, neural networks) and the Internet of Things (IoT) which requires that applications and their data to be scattered across multiple locations, edge clouds, multi-clouds and multi-data centers.

Owing to Distributed Cloud Computing technologies, Internet service developers will no longer focus on software and hardware infrastructure capabilities, but they could focus on providing efficient services to end users.

This paper aims to highlight the new concept launched by Gartner, Distributed Cloud Computing and ways of implementing it in the business environment. The study also considers that DCC is an approach which allows the development of IoT, enabling real-time processing of device requests, at the fog/edge nodes, where decisions must be made quickly. In the model shown, all these clusters of disparate micro-clouds are centrally connected and managed for Big Data storage and complex analysis.

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