From Cloud Computing to Fog Computing and IoT Development

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Abstract

Internet of Things is considered one of the most trending topic in the world of Information Technology. The Internet of Things is a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes and virtual personalities, use intelligent interfaces and are seamlessly integrated into the information network.

While Cloud Computing can today be considered well established, modern application domains such as IoT, autonomous driving, or even mobile applications trying to tap the full potential of future 5G networks require an extension of the cloud towards the edge, thus, naturally leading to the new Fog Computing paradigm. Fog computing is enhancement of the cloud-based network and computing services. Fog Computing extends the Cloud Computing paradigm to the edge of the network, thus enabling a new breed of applications and services.

This paper presents the current state-of-the-art in the field of fog computing and aims to provide detailed survey. It also includes challenges and opportunities in the fog computing and various possible solutions to overcome those challenges.

Keywords 1

Internet of Things, Cloud Computing, Fog Computing

1. Introduction

New emerging digital technologies such as artificial intelligence, virtual reality, augmented reality, cloud computing, blockchain, robotization, the Internet of Things, big data, etc. have produced a powerful disruptive effect in almost all areas of our existence and have radically changed the way we live, work, learn or relax. Without consciously realizing it, everyone is adapting to the digital era. The potential benefits of Internet of Things are limitless and IoT applications are changing the way we work and live, opening new opportunities for growth, innovation and knowledge creation. Internet of Things [2] is a concept and a paradigm that considers pervasive presence in the environment of a variety of things that through wireless and wired connections and unique addressing schemes are able to interact with each other and cooperate with other things to create applications or services. The goal of the Internet of Things (IoT) is to enable things to be connected anytime, anyplace, with anything and anyone using any network and any service. This new technology has a major influence on the economic [1] and social fields, and also on education, healthcare systems, energy management, environment monitoring, and smart cities by associating everyday objects with Internet capabilities and Big Data analytics. IoT is developing in two directions: increasingly smarter physical devices and environments and ubiquitous interconnection. Fog computing [8] is a methodology of network that transfer the data from the location, where it is actually created to where it has to be stored, whether that's a cloud or any customer operated data centre. It creates a distributed network which connects different environment and make association between cloud computing and IoT. This paper begins by introducing and describing the internet of things definition and characteristics. Section III discusses cloud

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computing and IoT and Section IV presented all the aspects of Fog Computing as definitions, architectures and discusses fog computing characteristics and IoT development. In Section V we conclude this study.

2. Internet of Things-IoT, Definition and Characteristics

The internet today is getting connected to a very large number of devices or sensors of IOT. These numbers were not envisaged previously. IoT or Internet of Things, alternatively known as IOE, Internet of Everything envisages connecting more and more consumer electronic devices, home appliances, medical devices, cameras, all types of sensors for temperature, pressure or humidity, etc., in addition to mobile phones and industrial IoT devices. The Internet of Things [3] is a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes and virtual personalities, use intelligent interfaces and are seamlessly integrated into the information network. Things are "smart objects", meaning they are capable to collect data from the environment and communicate with the entire system. At the first level there are sensors, microprocessors and communication equipment followed by the level containing the operating system for these objects [4]. There are rich variety of technologies which are covered by the internet of things and they are industrial internet of things IoT, internet of services, customer IoT, Industry 4.0, and many more. However, these technologies cannot completely function on themselves without the assistance of the technologies like the edge computing, cloud computing, big data analytics, machine learning and a few more and all this is for the gathering and processing the data such that they can be used for betterment of the operations. The IoT [7] is considered as the future evaluation of the Internet that realizes machine-to-machine learning. The basic idea of IoT is to allow autonomous and secure connection and exchange of data between real world devices and applications. The IoT links real life and physical activities with the virtual world. The numbers of Internet connected devices are increasing at the rapid rate. These devices include personal computers, laptops, tablets, smart phones, PDAs and other hand-held embedded devices [5]. Most of the mobile devices embed different sensors and actuators that can sense, perform computation, take intelligent decisions and transmit useful collected information over the Internet. According to data published by Statista, at present IoT is spreading at a rapid pace and as of 2019 the connected devices throughout the world were 27 billion, and as of 2025 about 75 billion connected devices will exist.

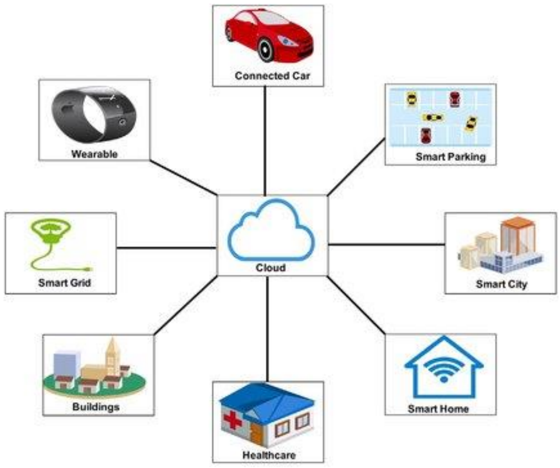

Figure 1: Centralized IoT Architecture

There are four essential characteristics for a device to be considered a ‘thing’ in IoT terms:

1. The device must be capable of collecting and transmitting data: IoT devices need to exist in environments in which information can be collected and either sent to another device or directly to the Internet.

2. The device must have the ability to operate with action-based responses: IoT devices can be programmed to act according to particular conditions.

3. The device must have the ability to receive information: IoT devices must be able to receive information from the network.

4. The device must be able to support communication: IoT devices by nature belong to a network of devices that can communicate with each other through other nodes in the same network.

Internet of Things is one of the most revolutionary technologies developed in the twenty first century which has seen rapid growth and spread in various sectors of livelihood. With more and more applications of IoT getting developed day by day, its usage in the industrial, healthcare, and manufacturing and more recently in the field of education as well.

3. Cloud Computing and IoT

At a basic level, cloud computing is a way for businesses to use the internet to connect to off-premise storage and compute infrastructure. In the context of the Internet of Things, the cloud provides a scalable way for companies to manage all aspects of an IoT deployment including device location and management, billing, security protocols, data analysis and more. Cloud services [9] also allow developers to leverage powerful tools to create IoT applications and deliver services quickly. On-demand scalability is key here given the grand vision of IoT; a world saturated with smart, connected objects. Many major technology players have brought cloud-as-aservice offerings to market for IoT. Microsoft has its Azure suite, Amazon Web Services, a giant in cloud services, has an IoT-specific play, IBM offers access to the Watson platform via its Bluemix cloud, and the list goes on and on.

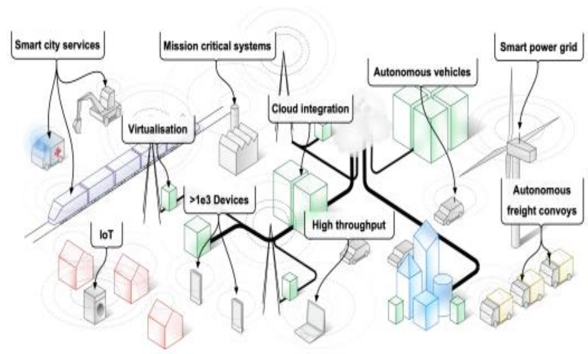

Figure 2: Smart and Wireless Environment

4. From Cloud to Fog Computing

A new paradigm known as Fog Computing was emerging, which seamlessly integrates the edge devices on one hand with the cloud resources on the other, to overcome all the limitations of Edge Computing as well. Fog computing [10] has been initially introduced in the telecommunication sector when researchers and practitioners realized how the role of the final users changed from consumers of information to prosumers, producers and consumers at the same time. In fact, the original paradigm on which the Web is based assumes that the core of the network is in charge of providing information that will be consumed at the edge. Cloud computing offers many possibilities for prospective users; there are however many different storage and compute services to choose from between all the cloud providers and their multiple datacenters. Fog computing, an extension of cloud computing services to the edge of the network to decrease latency and network congestion, is a relatively recent research trend. Although both cloud and fog [19] offer similar resources and services, the latter is characterized by low latency with a wider spread and geographically distributed nodes to support mobility and real-time interaction. Prosumers with mobile devices or IoT sensors, however, generate immense data quantities at the edge of the network. So, what precisely is Fog Computing and how can it be distinguished from Edge Computing? Edge Computing is exclusively about computation at the edge of the network without any notion of cloud services. Depending on the source, Fog Computing [11] is either the same as Edge Computing or is defined as the amalgam of cloud, edge, and any intermediary nodes in between (this could be small- to medium-sized data centers within the core network of the network provider. Fog Computing must be more than creating a data center in the box, i.e., Cloudlets, to bring the cloud closer to data producers. Instead, Fog Computing must be seen as a ―resource layer that fits between the edge devices and the cloud data centers, with features that may resemble either. The goal of Fog computing is to decrease the involvement of cloud by filtering out data, which is produced by the rising number of sensors. Instead of generating centralized data center, the processing of computational task should be performed on multiple devices in network [12]. Since the latency calculation in fog computing start from the end device to cloud, it reduces the latency and bandwidth utilization in network. In Fog computing, latency rate is calculated from edge devices to fog nodes. This modified utilization of edge resource provides faster communication. This paradigm [13] has to provide the power of execution, monitoring and analyzing IoT services. As also pointed out by the Open Fog Consortium, the goal of Fog Computing is to provide a set of methods and tools to create a continuum between edge and cloud. For this, Fog Computing [14] technologies especially need to enable fluid data movement between cloud services and edge, in both directions, while satisfying application constraints in terms of quality of service (QoS). Such data movement may also be accompanied by movement of computation – both in the same way and in a complimentary fashion compared to data movement. In an IoT environment, it is important to understand the relationship between Fog and cloud computing and assess the impact of fog computing on the IoT service delay and quality of service. Fog computing [22] paradigm offers several features, which make it suitable for IoT enabled systems. These include low latency due to close proximity of the fog services near the network edge, conservation of network bandwidth due to transmission of selective and filtered data, and increased response time due to shorter physical distance between data source and fog nodes relative to the cloud. Fog computing is a heterogeneous [15] hyper distributed cloud infrastructure paradigm, ranging from small compute nodes close to the end-users to traditional distant data centres. With greater proximity to the end users, delay and jitter in the delay can be reduced, and intermediate network reliability improved.

4.1. Characterization of Fog Computing

According to IDC, 45% of the data worldwide will move closer to the network edge by 2025, and 10% of the data will be produced by edge devices such as phones, smart-watches, connected vehicles, and so on. Fog computing is believed to be the only technology that will stand the test of time and even beat Artificial Intelligence, IoT app development, and 5G in the next five years. Cloud and fog computing [17] share overlapping features, but fog computing has additional attributes such as location awareness, edge deployment and a large number of geographically distributed nodes in order to offer a mobile, low latency and real-time interaction. It is a highly virtualized platform that offers storage, compute, and networking services between the traditional cloud computing data centers and end devices. Fog computing can be characterized by low latency, location awareness, edge location, interoperability, real-time interaction between data and cloud, and support for online interplay with the cloud. Fog applications [21] involve real-time interactions instead of batch processing, and they often communicate directly with mobile devices. Fog nodes also come with different form factors, deployed in various environments.

4.2. Characteristics of Fog Computing

Fog computing possess various characteristics, some of them are listed below: Heterogeneity: Fog Computing is a highly virtualized platform that yields compute, storage, and networking services between end devices and traditional Cloud Computing Data Centers, typically, but not elite located at the edge of network. Compute, storage, and networking resources are the building blocks of both the Cloud and the Fog . Edge location: The origins of the Fog can [18] be traced to early proposals to support endpoints with rich services at the edge of the network, including applications with low latency requirements (e.g. gaming, video streaming, augmented reality. Geographical distribution: In sharp contrast to the more centralized Cloud, the services and applications targeted by the Fog demand widely distributed deployments. The Fog, will play an active role in delivering high quality streaming to moving vehicles, through proxies along highways and tracks.

4.3. Architecture of Fog Computing

In a traditional network, centralized hub can’t maintain high volume data which is created by different devices or transactions. Old data warehouse model techniques can take more response time and can’t get the low latency rate as required by users [7]. Fog computing delivers facilities with low latency and less traffic congestion [14]. The fog layer contains geo- distributed fog servers those process computations at the end point of system. Each fog server has equivalent computing capabilities to process a huge amount of workload at the edge. Thus, a very less amount of workload is moved to the cloud for storage purpose and analytic processing. Therefore, fog computing becomes a major driver of the IoT in education systems. The connected devices are increased which produces a large amount of data and connectivity of that data to a central cloud is become possible [19]. Fog computing provides the facility for analyzed the data locally and to choose what kind of data needs to transfer to centralized cloud.

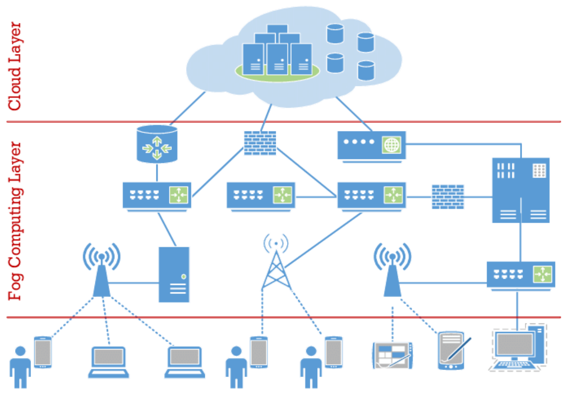

Figure 3: Fog Computing Architecture

4.4. Fog computing and IoT app development the connection

There are almost 31 billion IoT devices in use as of today. No wonder we produce 2.5 quintillion bytes of data per day. It is obvious we need an alternative to the traditional method of handling data. That is where fog computing enters the picture.

When an application or a device collects enormous volumes of information, efficient data storage becomes a challenge, not to forget, costly, and complicated. Heavy data puts a load on the network bandwidth. Setting up large data centers to store and organize this data is expensive!

Fog computing [20] gathers and distributes storage, computing, and network connectivity services, reduces energy consumption, enhances the data's performance and utility, and minimizes space and time complexity. While Fog nodes provide localization, therefore enabling low latency and context awareness, the Cloud provides global centralization. Many applications require both Fog localization, and Cloud globalization, particularly for analytics and Big Data.

4.4.1. Smart cities

Data centers are not developed to handle the growing demands of smart city apps. As more and more people started using more IoT devices, more data would be transmitted and accessed. Fog computing can help such ill-equipped smart grids to deliver the actual value of IoT app development. Large-scale sensor networks: To monitor the environment and the Smart Grid are other examples of inherently distributed systems, requiring distributed computing and storage resources. Very large number of nodes, as a consequence of the wide geo-distribution, as evidenced in sensor networks in general and the Smart Grid in particular. Support for mobility: It is essential for many Fog applications to communicate directly with mobile devices, and therefore support mobility techniques, such as the LISP protocol, that decouple host identity from location identity, and require a distributed directory system. Real-time interactions: Important Fog applications involve real-time interactions rather than batch processing.

4.4.2 Utilities

The term "utilities" includes applications for hospitals, transportation, law enforcement, and so that need the latest technology to deliver data to support their operations. For instance, information about carbon emissions, potholes on the road, and water leakages can be used to update billing information, save lives, and improve operations.

4.5. How Fog computing enhances the value of the Internet of Things solutions

IoT and end-users are becoming increasingly powerful. A large amount of data is now being processed directly on the cloud. Adding to that, here are six benefits that fog computing can deliver to the IoT app development process:

1. Greater business agility

With the right tools, you can build fog applications and deploy them as needed. Such applications program the device to operate in the way a user wants.

2. Better security

Fog computing acts as a proxy for resource-constrained devices and updates their software and security credentials. It deploys fog nodes using the same policy, procedures, and controls used in other parts of the IT environment.
When data is processed by a large number of nodes in a complicated distributed system, it is easier to monitor nearby connected devices' security status.

3. Network bandwidth efficiency

Fog computing enables fast and efficient data processing based on application demands, computing resources, and available networking. Pieces of information are combined at different points instead of just sending them to one data via one channel.
This reduces the volumes of data required to be transferred to the cloud, thus saving network bandwidth and considerably reducing costs.

4. Uninterrupted services

Fog computing can run on its own and ensure uninterrupted services even when the network connectivity to the cloud hampers. Moreover, due to multiple interconnected channels, loss of connection is almost impossible.

5. Improved user experience

Edge nodes run power-efficient protocols such as Zigbee, Bluetooth, or Z-Wave. Fog computing enables instant communication between devices and end-users, irrespective of network connectivity, thus enhancing user experience.

5. Conclusions

In this survey we have comprehensively presented all the aspects of Fog Computing as definitions, characteristics and architectures. In Fog Computing, application services run on both edge nodes with low latency access but very limited resource capabilities and in the cloud with higher access latency but practically unlimited resources as well as on possible intermediary nodes. Fog computing as a new paradigm is a yet virtually unexplored field that offers a number of open research challenges As demand for vast compute and storage needs have arisen, very nicely handled by public cloud providers. But the cost of transport and speed of processing has also increased, which is challenging for many uses cases such as mission-critical service. As a result, many IoT initiatives are now distributing this computing power across the edge network, data centers, and public cloud. Fog computing has the facility to connect everything and become a significate part of our environment.

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