Fog Necessity Over Cloud Computing for Healthcare Applications

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***Abstract*— The increased amount of data generated through the communication devices, hampered the manner of data storage locally in the computers. Innovative solution for dealing this problem are cloud computing systems. On the other side, smart devices, as a part of the rapid technology evolution, become an important part of our daily lives, to the extent that the quality if our lives depend on them. This led to a necessity for development of new technological architecture that will support the cloud systems towards overcoming their drawbacks appearing at the edge network. In that direction, fog computing is a novelty that solves the cloud issues by placing the computational analysis and storage closer to the network edge. In this paper, the effect of fog computing paradigm in healthcare applications is investigated with respect to the latency and network usage. A detailed analysis regarding both performances are proved, first, when only cloud environment is present and then when fog computing is added. The results prove that managing data closer to the network edge, or by applying fog, decreases latency and network usage by a considerable amount, than compared to transferring data to the cloud which increases the network traffic congestion.**

Keywords*— *Internet of Things (IoT), fog computing, cloud computing, sensors, healthcare.

I. Introduction

In todays' world whether it will be a smartphone, a smart car, or a juice dispenser we are bound to use the technologies and this have become an important part of our lives. Their massive usage creates a significant amount of data every day [1]. In old times the purpose of internet was to connect two or more end-users and their generated data was stored in the computers' memory locally. By a time as the quantity of generated data starts increasing, the computer's memory became limited and insufficient to handle this issue. This lead to a shift in the technology, which is known as cloud computing [2].

With its emergence, cloud computing became the number one solution for storing and processing data. Since it offers a centralized computing model with a high computation power, efficient network management functions and storage capability has grown to crucial solution for companies that were looking for scaling their computational operations [1], [3]. Data centers being located close to the core network makes data transfer difficult in sense of producing significant amount of time for its realization, known as latency. Latency is an important drawback in cloud computing systems, especially, for applications and situations that are time sensitive, like, real- time applications.

Although cloud computing has its benefits, the extensive increase of devices connected to internet, known as Internet of Things (IoT), poses a challenge for the usage of cloud computing [1], [3]. By Cisco Systems [4] it is predicted that an estimated 50 billion "things" will be connected to the internet by 2020. But the cloud models are not designed in a way that can meet the needs of IoT, which motivates the emergence of a new technological paradigm called fog computing. In this paper, we will focus on the advantages that comes with the new technology, emphasizing the two parameters improved latency and network usage that are evident at the end users. Both parameters will be analyzed and compared applying healthcare applications, when only cloud computing environment is considered and then when fog computing is added. The results show that the trend of massive data production cannot be served enough quality, without the use of fog computing.

The paper is organized as following: Section II gives comparison between the cloud and fog architecture. Section III gives overview of existing literature. Section III explains for the importance of fog in healthcare application and section IV shows the results. Section V concludes the paper.

II. Cloud vs. Fog Computing

Traditional cloud computing architectures move all the data from the network edge to the cloud. The data is stored in data centers. After being analyzed in cloud the required actions are taken and the required data is transferred back to the end- users. But the bigger the data is, the longer the transfer time becomes. Access time is one of the most important points to be considered, as the purpose of IoT is to enhance peoples' life quality, [5]. Table 1 gives a comparison of cloud computing versus fog computing discussing the advantages and disadvantages of both technologies with respect to the most important aspects. We see that both cloud and fog have high complexity level. On one hand, fog is more advantageous in the means of response time, mobility, distance to end-devices, communication mode, bandwidth costs, energy consumption, location awareness, and geo-distribution. On the other hand, cloud is more advantageous when it comes to computational and storage capability.

TABLE I. Cloud Computing vs. Fog Computing

Operates on	**Cloud** **cloud**	**Fog** **network edge**
Complexity level	high	high
Response time	high	low
Mobility	limited	supported
Distance to end-devices	far	close
Communication mode	IP network	wireless
Bandwidth costs	high	low
Computation capability	strong	weak
Storage capability	strong	weak
Energy consumption	high	low
Location awareness	no	yes
Geo-distribution	centralized	decentralized

Fog computing was introduced to tackle the limitations of cloud computing, and its main goal is to increase scalability and reduce bandwidth. Cloud system is still the number one solution for the storage of big data but the needs has changed.

Although storing data is still important, it is not the only important issue. IoT generates data constantly and in many situations rapid analysis is required [6], [7].

Fig. 1 shows the hierarchical architecture of fog computing consisting of three layers. Cloud layer consists of multiple high performance servers and provides high storage capacity and powerful computing capabilities. Fog layer consists of fog nodes and is located at the proximity of the end-users.

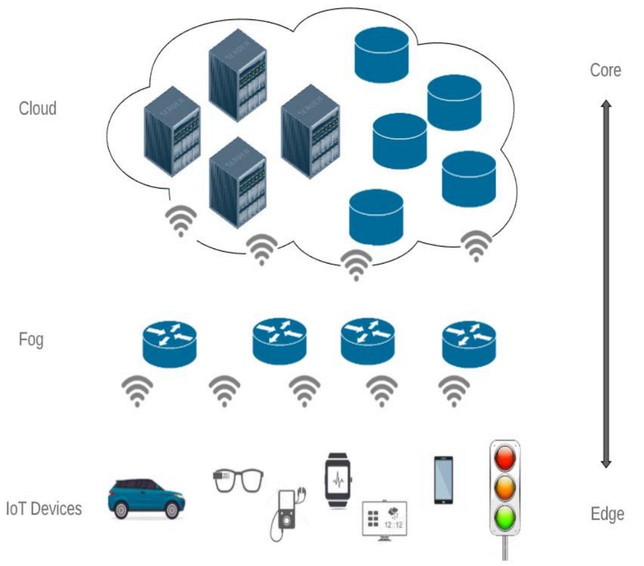

Fig. 1. Hierarchical architecture of fog computing.

Fog nodes are widely distributed and can be static or mobile. Terminal layer it is the layer closest to the physical environment. It consists of various IoT devices that are responsible for sensing and collecting the data. In this architecture the fog nodes are connected to the fog layer by wireless technology, and can also be interconnected. If they are interconnected, the intercommunication is made possible via wired or wireless network.

IoTs' concept is incompetent when it comes to conceptual power, battery, storage and computing abilities. Therefore it needs the support of a more complex and strong concept, i.e. the fog computing layer [8], [9].

When a new technology arises it often takes time to come into a consensus about its definition. The most comprehensive yet simple definition is given by L.M. Vaquero et al. [10], as "a scenario where a huge number of heterogeneous (wireless and sometimes autonomous) ubiquitous and decentralized devices communicate and potentially cooperate among them and with the network to perform storage and processing tasks without the intervention of third-parties."

III. Related Works

L.M. Vaquero et al. [10], in their paper, have discussed fog computing on the domain of device ubiquity. They have examined two of the most important aspects of technology and technological devices, the size and battery lifespan, in the meaning of cost, portability and power consumption. Finally they have come to a conclusion that "the fog is nothing but the convergence of a set of technologies that have been developing and maturing in an independent manner for quite some time". Stojmenovic et al. [11] have addressed on a very important issue, and that is the security. The main focus is on the security and privacy issues and they have discussed these issues by investigating a typical attack, known as the man-in-the-middle attack in detail. In a paper published by Cisco Systems [4], which is the worldwide leader in networking for internet, they have proposed a definition for the fog computing and discussed how the fog work. A comparison of cloud versus fog is done with respect to response time, application examples, how long IoT data is stored, and geographic coverage.

P. Hu et al. [3] have discussed the motivation behind the emergence of fog computing. While they have worked on the architecture of fog computing they have also analyzed the key technologies fog computing depends on. The authors have also discussed the applications of fog computing through real life scenarios.

M. Ahmadi et al. [8] have worked on the shift of technological paradigm and how it has shifted from cloud computing to fog computing. The authors have discussed both the advantages and the challenges of this new technological paradigm with a touch on reliability, security, management, availability, privacy, interoperability and applicability.

IV. The Importance of Fog Computing for Healthcare Applications

Healthcare is the most fundamental issue in human life. Unfortunately, as the time changes and the world evolves humankind is facing new diseases and chronic illnesses. This in turn creates the demand for resources. This high demand puts a lot pressure on the healthcare systems [6],[12].

The focus in healthcare has shifted from treating patients at hospital after an incident to delivering a high – quality healthcare to prevent serious incidents or illnesses. The first steps towards achieving this goal is monitoring the conditions of healthy people in order to keep them out of hospitals. But monitoring people individually in hospitals is impossible. Therefore it is safe to say that the solution is remote monitoring. Sensors will also provide accurate and precise measurements of peoples' health conditions, since they are capturing data continuously [13].

The system architecture of a cloud – based IoT healthcare application is mainly composed of three layers. The wearable sensors, i.e. devices that are connected to the patients'/users' body. Once they are turned on they start to collect data about the patients' health. Smart phones provide an interface for the data to be sent to the cloud datacenter. Additionally, smart phones ask for user authentication. Cloud data center keeps all the data collected. The essential data is being extracted from the raw data and is simplified for further use. After the analysis the users' health conditions are being evaluated and if necessary the user or the doctor is notified.

The system architecture of fog – based healthcare applications, in addition to cloud – based applications, have and additional layer between the smart phones and the cloud datacenter, the fog layer, which has specialized networking devices called "fog nodes". These fog nodes are used for and capable of performing computational tasks, storing information and simplifying the massive amount of data since not every data collected need to be sent to the cloud. These data are eliminated in the fog layer, and access to the needed part of the massive data is being made easier. Fog nodes can be activated and/or deactivated as and when needed [14].

V. Results

In order to give a better insight about the differences between cloud and fog computing we will discuss their system architectures in healthcare applications and analyze the results of several studies. We are going to compare the results of four different simulation experiments with a focus on network usage and latency. The simulation experiments that use only cloud is done using the CloudSim toolkit, which is a widely used library for the simulation of cloud – based environments. The simulations that use the fog layer are done using the iFogSim, which is an open source toolkit used to model and simulate the networks of edge computing, IoT and fog computing.

In [15] authors have proposed a "tri-tier architecture for context – and latency – sensitive health monitoring using cloud and fog computing". The aforementioned tri-tiers are the sensors, fog computing, and cloud computing where the sensors work in conjunction with one another. The flow of information between these levels has to be managed efficiently, privately, and securely. The sensors tier, which consists of wearable devices, gather the data and send it to the fog tier. The fog computing tier aggregates the data that comes from the sensor tier and perform the first data analysis, then distributes the processing work to the related fog nodes for further analysis. The cloud computing tier manages the actions that need to be performed by the health monitoring system. Finally the health monitoring system consists of the region, the institution, the clinical department, and the individual doctor, nurse, or patient.

In this experiment several test runs and are simulated for five different configurations of monitoring devices. Five configurations are considered, config1, config2, config3, config4, and config5, they each have by 4, 8, 16, 32, and 64 monitoring devices, respectively. This means that each configuration will give different results during the simulation process. In Table 2, Fig. 2, and Fig. 3 we see the results of the simulation experiment for each configuration both with and without fog layer. We see that applications with the fog layer outperforms the applications using only the cloud layer.

TABLE II. Comparison of Percentages

Physical Topology	**Average Latency (ms)**		**Network Usage (KBs)**	
	Cloud only	***With fog layer***	***Cloud only***	***With fog layer***
Config1	210.38	8.47	130	12
Config2	210.78	8.47	351	22
Config3	211.57	8.47	672	53
Config4	1283.86	8.47	1061	98
Config5	3225.91	8.47	1102	189

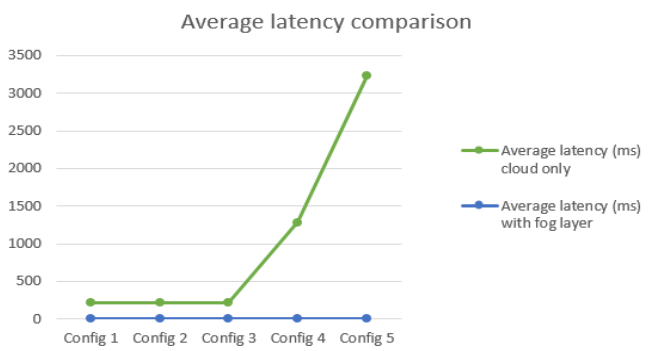

Fig. 2. Average latency comparison.

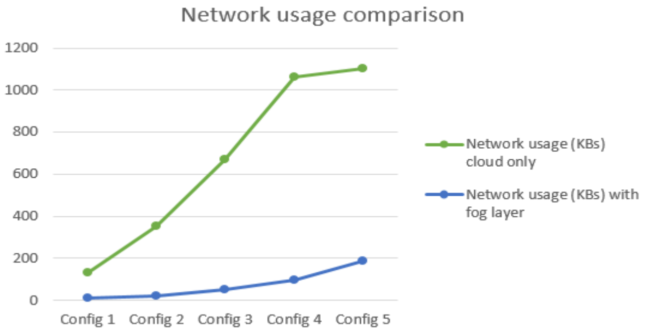

Fig. 3. Network usage comparison.

Reference [16] simulate different configurations for different fog nodes. The application that is being analyzed is an healthcare application that processes heart patients' data. Considering the number of the requests lunched by the patients, network usage, and latency is being compared for architectures with and without fog computing. Table 3 and Fig. 4 displays the results of this experiment. The study has shown that fog assisted application architecture manages the data of heart patients much more efficiently.

TABLE III. Performance Comparison

Environment	**Average Network Usage Time (s)**	**Average Latency (s)**
Cloud Computing	84.58	24.33
Fog Computing	23.36	8.3

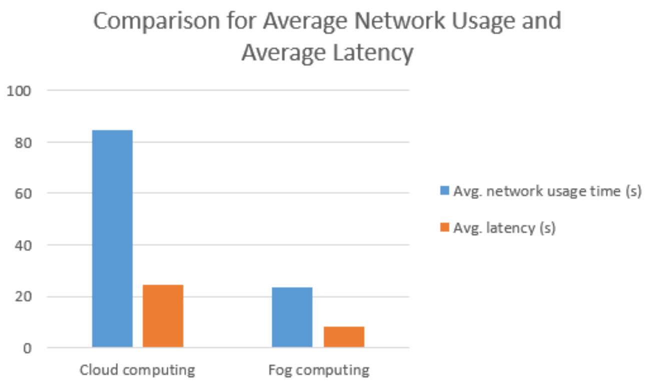

Fig. 4. Comparison for Average Network Usage and Average Latency.

P.H. Vilela et al. [17] test a fog assisted approach under two different experimental scenarios. The first scenario consists of only the cloud layer, whereas the second scenario includes the fog layer. In the proposed healthcare application the sensors include environmental sensors, i.e. sensors measuring room's humidity, noise level, and temperature, and medical sensors, i.e. sensors measuring body temperature, blood pressure, and heart beat rate. After 30 experiments, the Central Limit Theorem was used to obtain an average. The study concludes that for one minute data transfer time there is 0.25 seconds of delay. On the other hand, as the number of the sensors increase the network usage decreases more than by half if a fog layer is used.

In [18] authors proposes an energy – efficient strategy which allocates the incoming tasks according to the remaining CPU capacity and energy consumption. In other words, this approach takes into account the distance of each fog node to the sensor. Moreover the proposed strategy tries to use the fog nodes efficiently, and ensures it is neither underused nor overloaded. In this case study the energy efficiency of the proposed strategy is evaluated by remotely monitoring patients with diabetes. For simplicity the patients' were equipped only with the blood glucose sensor. Four different configurations with different workloads were considered. The configurations consist of 2 fog devices and 4 smartphones, 4 fog devices and 4 smartphones, 4 fog devices and 8 smartphones, 4 fog devices and 16 smartphones respectively. The results show that the use of fog layer significantly reduces the latency, particularly in the third and the fourth configurations, i.e. the configurations with the higher number of sensors. The same results hold for the network usage. Using fog nodes reduces the amount of data transmitted over the network, decreasing the network usage. Although this is true for all four configurations, the proposed strategy is particularly better in configurations three and four, i.e. the configurations with heavier workloads.

VI. Conclusion

With the most important aspects being discussed it is important to remember that healthcare industry is still in its infancy stage and is open for improvement. With this in mind, it has to be appreciated the long way it has come. For now fog computing is considered as the best method to rely on because it uses shared resources which affects its performance in a way that meets the requirements of healthcare IoT applications. Nevertheless the applications should be designed very carefully because they are time-sensitive but for more complex tasks more fog nodes can be needed. Though scalability is one of the most important advantages of fog computing, increasing the number of fog nodes increases the probability of failure.

It is safe to say that fog computing is the most suitable technology for time-sensitive applications and particularly for healthcare applications. All four studies discussed in this paper demonstrates clearly that fog computing outperforms cloud computing with respect to latency and network usage.

Keeping this in mind one should not forget that outsourcing data analytics fully to the edge of network may result in unwanted consequences arising from limited computational capacity of the edge nodes. Many applications require both fog localization and cloud globalization to operate in the best manner. Therefore, the distribution of functions between the cloud and the fog nodes is a crucial factor.

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