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Efficient Resource Allocation for Time-Sensitive IoT Applications in Cloud and Fog Environments

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Abstract: Nowadays, with the quick development of internet and cloud technologies, a big number of physical objects are linked to the Internet and every day, more objects are connected to the Internet. It provides great benefits that lead to a significant improvement in the quality of our daily life. Examples include: Smart City, Smart Homes, Autonomous Driving Cars or Airplanes and Health Monitoring Systems. On the other hand, Cloud Computing provides to the IoT systems a series of services such as data computing, processing or storage, analysis and securing. It is estimated that by the year 2025, approximately trillion IoT devices will be used. As a result, a huge amount of data is going to be generated. In addition, in order to efficiently and accurately work, there are situations where IoT applications (such as Self Driving, Health Monitoring, etc.) require quick responses. In this context, the traditional Cloud Computing systems will have difficulties in handling and providing services. To balance this scenario and to overcome the drawbacks of cloud computing, a new computing model called fog computing has proposed. In this paper, a comparison between fog computing and cloud computing paradigms were performed. The scheduling task for an IoT application in a cloud-fog computing system was considered. For the simulation and evaluation purposes, the CloudAnalyst simulation toolkit was used. The obtained numerical results showed the fog computing achieves better performance and works more efficient than Cloud computing. It also reduced the response time, processing time ,and cost of transfer data to the cloud.

Keywords

Fog Computing, Networks, Cloud Computing, IoT, Data Center, CloudAnalyst

I. INTRODUCTION

In a strive to improve the quality of life and to make use of the available technologies (such as fast and reliable internet connections), a large number of physical objects have been inter-connected and linked to the Internet. Almost everything (from home appliances, medical devices, cars thermostats, monitoring and control systems that enable smart homes) communicate and interact with each other. All these objects (which act as sensors and actuators) and the connections between them represent the Internet of Things (IoT) [1]. The number of connected devices and of available applications raises day by day. All the statistics point to potentially significant and fast-paced growth of the IoT in the near future.

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IoT will be the Internet of the future and it is estimated that the IoT will have an economic impact of 11 trillion dollars per year by 2025 [2]. This rapid development of IoT is fueled by advances in various areas which does not include only complex devices such as mobile phones energy distributions and storing (batteries) and communications but also simple objects like sensors (temperature, pH, etc…) [1]. Being centralized and connected to an internet environment, there are many domains and environments in which the IoT can play an important role and improve the quality of our lives [3]. As a high quantity of data will be generated by each device, it will require processing and analysis for better insights. Therefore, Cloud Computing plays a major role in processing data from IoT. The National Institute of Standard and Technologies defines Cloud Computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.” [1]. Therefore, Cloud Computing has strong sources of data processing from Internet objects and large storage space. Users do not need to worry about buying storage because the storage is scaled as the data generated increases and the user pays only for the consumed storage [4, 5]. It is estimated that, in the next two decades, the demand for Cloud Computing services will be further increased. In addition, although Cloud Computing satisfies many demands and provides processing and storage services, it is not able to satisfy many requirements for applications such as emergency, time-sensitive and real-time and health monitoring applications. This is due to the fact that there is a delay for transferring the data into and from the cloud and there is a heavy network usage; the network bandwidth is not scalable and the high energy consumption in the cloud increases with the enormous amount of data produced by IoT. In addition to the issues unresolved in IoT applications that often need mobility support, geo-distribution ,and location-awareness. Finally, some users have concerns about privacy when sending their data in a cloud processing center. In order to overcome these limitations, to enhance the cloud and to improve the performance of the time-sensitive applications, fog computing was proposed. It supports the cloud and all types of IoT applications. Fog computing is the new computing model that extends the cloud computing services to the edge of the network or closer to the edge to reduce the network usage, the latency of the application and energy consumption [4].

In [6], the Fog Computing is defined as "a scenario where a huge number of heterogeneous devices communicate and potentially cooperate among them and with the network to perform storage and processing tasks". This definition includes many features and due to the overlapping of terms, for some users, the Cloud Computing and Fog Computing are difficult to grasp. Section 2 presents the common and the distinct features of Cloud and Fog and their integration with the IoT.

II. LITERATURE REVIEW

IoT is a paradigm that adds a new dimension to the modern wireless telecommunications by enabling communications with and among smart objects, thus resulting to the dimension of ''*anytime, anywhere, any media, anything"* communications. The idea of this concept is a network of physical "Thing" or objects embedded with electronics, operating system (OS) and network sensors that enable it to achieve information and service by interacting through internet (with advanced communication protocols and without human involvement) with each other and the manufacturer, devices and other connected operators.

The word 'things' in IoT term refers to any object in the world with an embedded network sensor, whether it is a smart communication device or an idle object. The backbone of IoT can be considered the Machine-to-Machine (M2M) communication. In M2M, communication between two machines takes place without any human interaction. For examples like smart home and e-Health applications. Huge quantity of data can be produced by billions of connected devices and transmitted through the networks to the Internet [7]. IoT must be capable of integrating thousands of heterogeneous objects. Therefore, flexible layered architecture is a must [3]. The basic IoT architecture is comprised of 3 layers (application, network ,and perceptions) but the literature presents models that add more abstraction [3]. The common aspects between them is represented by a five layer model that includes[3]: i) perception layer (where physical sensors are used to collect and process information); ii) object abstraction layer (that transmits the data from the first layer -perception- to the next -service management-); iii) service management (which pairs the services and requester); iv) application layer (provides the data to the user); v) business layer (where the overall activities and services of the IoT are managed).

2.1. Cloud Computing

Cloud computing is a network model, that takes the computing from the user to the Internet, and frees the end user from maintenance and resource management. Cloud computing enables convenient, on-demand network use of a shared pool of configurable computing resources and enable access to the content. It simplifies the client's computing tasks by hiding storage and computing details. Figure 1 shows the interaction of IoT with the cloud via the internet [7].

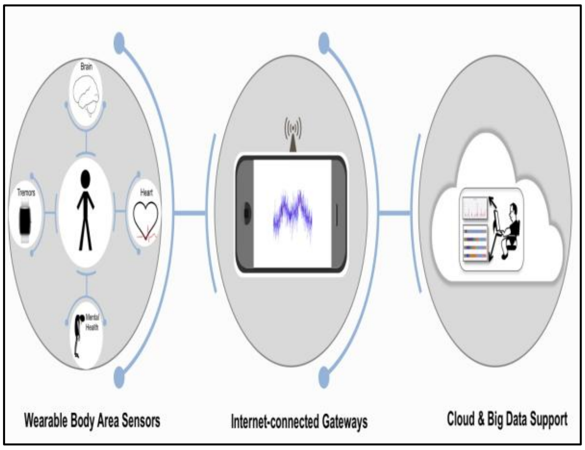

Figure 1 Interaction Of IoT With Cloud Via Internet [3]

Cloud computing refers to processing, configuring, and accessing hardware and software resources remotely. It provides online data storage, an infrastructure and access to application utilities through the internet. It allows us to create, configure and customize an application online. There are two basic working models of cloud [8]:

- **Service Models**. Service Models are models where the cloud provider services can be chosen according to the specific needs of each user. They can be categorized into three basic models as the following: i) Software as a Service (SaaS): enables the user to pay for any service or application to access it from anywhere any time from the cloud; ii) Platform as a Service (PaaS): enables the user to pay for the access to the platforms and allows deployment of user applications and software in the cloud; iii) Infrastructure as a Service (IaaS): enables the user to manage and control the systems in terms of the applications, operating systems, network connectivity and storage without the need to control the cloud infrastructure
- **Deployment Models**. The deployment models are classified in accordance with the services and users' requirements as follows. There are four different models: i) Private Cloud: some particular institutions deploy, operate and maintain cloud infrastructure and not allow it to share with other institutions. ii) Community Cloud: A number of organizations with common needs and interests participate in the community cloud computing infrastructure. ii) Public Cloud: The general public can access public cloud computing infrastructure services on a commercial basis by a cloud service provider. iii) Hybrid Cloud: it is a combination of clouds of any types; for example, it could be a combination of public and private clouds or public or community cloud.

The integration of Cloud Computing and IoT was referred to as CloudIoT [1] and it is expected to be a disruptive technology as IoT able to use the vast resources provided by the Cloud. On the other hand, the Cloud can extend its scope through IoT and deliver new services

A general view about the integration concept of the cloud with IoT (as means to overcome the challenges of IoT related to data storage, scalability, and energy efficiency) is presented in [5], where it is mentioned that the huge amount of resources available on the cloud can help the limited capabilities of IoT. An added advantage is the quick low-cost installation and integration for complex data processing. The authors of [5] are aware of the relation of their work to existing literature and they showed how Cloud computing works as an extension of cloud computing and how it helps in latency. It is true that CoT solves some of IoT issues but also, it faces some challenges such as security and privacy. The architecture of CoT has three layers: application, perception and network layer.

2.2. Fog Computing

Fog computing is a new model that extends the cloud computing paradigm to the edge of the network (the entry point to the core network). The Fog converges a set of technologies that were developed over the years and represents their integration into a single scenario with requirements such as device ubiquity, agile network, efficient service management and data privacy [6]. Although both paradigms (Cloud Computing and Fog Computing) provide a similar set of services (in terms of processing, storage, etc.), Fog has an additional advantage related to its closeness to the user and its dense geographic coverage. The Basic element of the Fog Computing architecture is called a 'fog node', which is an extra layer added between an IoT device/data generating node and a remote cloud server. It brings basic analytic services, storage ,and networking services to the network edge, increasing performance by positioning computing resources closer to where they need to be (Figure 2). The aim of these fog nodes is to speed up time-sensitive applications. The services are hosted away from the cloud [7]. However, fog computing does not indicate that all the processes should be performed at the fog node; it promotes their use in the limits of realistic expectations [9]. Each device with computing, storage ,and network connectivity can be a fog node, like routers, industrial controllers, switches, and embedded servers. The fog nodes can be deployed anywhere with a network connection [10].

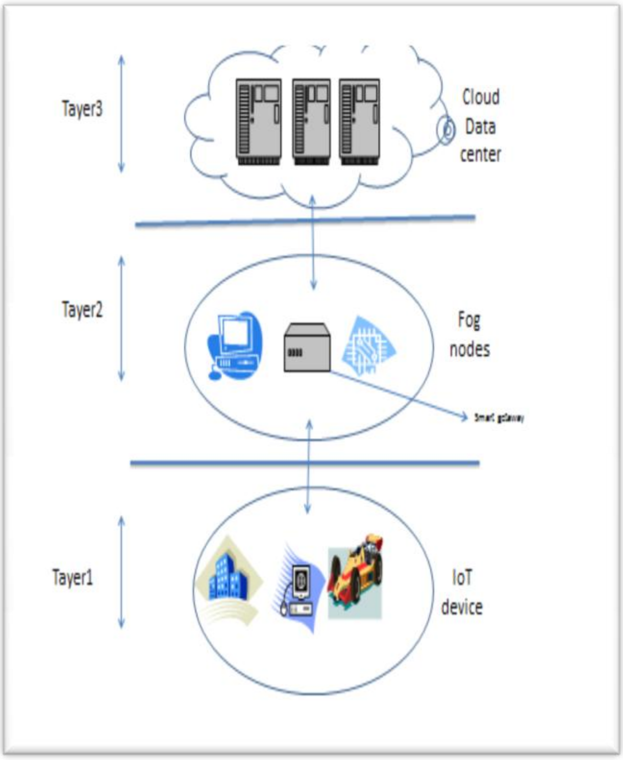

Figure 2 Basic Fog Computing Architecture [10]

Although fog computing costs more than using dumb devices, in the long term, the additional initial costs will lead to savings as the connectivity costs will be reduced, the battery-operated devices will have extended life cycles the dynamic and analytical setting will be easier to determine [9]

Besides the issues inherited from the Cloud, the Fog Computing faces new challenges such as: i) trust and authentication (where aspects such as trust model, rogue fog node, authentication must be addressed); ii) network security; iii) data storage security; iii) data computation security and privacy (where aspects such as verifiable computing, data search on encrypted files should be addressed)[11, 12]. In addition, edge devices have less computational resources (processing power, storage, memory), can only work with small amounts of data and have less knowledge about "the big picture" [9]

It was pointed out that increasing applications of the IoT and the need for a better and more automated infrastructure to handle with massive data produced by hardware, relying on cloud computing to achieve the goals of the Internet is not good and that the CoT team faces challenges [13]. One of these challenges is data pruning (because the data center in the cloud and the core networks are suffering from unnecessary communication). For this purpose, data can be pre-processed and reduced before being sent to the cloud. The authors discussed a "Smart Gateway" and presented the architecture of a smart gateway with fog computing. In their proposed system, the smart gateway (e. g., a router that is used for data transportation is a gateway node), which is an intermediate layer between

IoT and fog node, does some of the tasks starting from data collection to preprocessing, filtering, reconstruction, uploading only the necessary data to the cloud, keeping check on IoT nodes, and many others. However, we argue this system lacks the core of the fog concept. This system puts more intelligence and Interest on the gateway rather than the fog node. In the remote-sensing health care system, the sensors send a large amount of data from the human body and this leads to specific challenges when dealing with a huge amount of data [14]. In addition to diversity and homogeneity issues, the attempts to minimize the energy consumption of devices used in health care were discussed in [14]. The authors proposed a fog computing model to deal with the health care system. In the system architecture, only one fog node has been proposed to deal with data from remote sensors. However, we see that a single fog node in the fog layer is not enough to handle the sensitive data of the time, because, in the event of a failure at the serving node, due to system or network issues, the system loses its efficacy and hangs the system, thus leading to a delay in response. Comparison Between Cloud and Fog Concepts The main elements that distinguish the Fog Computing from the Cloud Computing are represented by: i) majority of the data is stored near the edge instead of sending it to the cloud, ii) uses local networks for transferring data to processing modes instead of core networks, iii) the majority of data is analysed at the fog nodes instead of using the cloud computing infrastructure, iv) the edge devices are self manages, controlled and governed [9] The authors of [15] provide a general view about the new developments in the area of executions mechanisms of cloud, fog and edge computing.

All the aspects are presented in a comparative manner, showing the advantages and disadvantages of each model.

The energy consumption of applications using centralized DCs in cloud computing was compared with the energy consumption of applications using nano data centers (nDCs) used in Fog computing [16]. Their results point to that nDCs might lead to reduced energy consumption depending on many factors like kind of applications, system design and so on.

III. METHODOLOGY

Cloud applications can be deployed in different locations. Due to geographic distribution, developers can face many issues when implementing user requests. In addition, the geographic distribution of the application affects its performance for existing users away from the data center. Therefore, before deploying Cloud and Fog applications in the real world, they should be tested on the simulation toolkit [17]. This section introduces two simulated scenarios of case studies for cloud and fog computing. Then a comparison between their results is performed using CloudAnalyst toolkit. Cloud Analyst is a toolkit developed at the University of Melbourne whose aim is to support evaluation and simulation of social networks according to the geographic distribution of users and data centers. It also allows to set the parameters' values for any cloud configuration. According to the parameters, the tool computes and shows the result in a graphical form. Figure 3 shows the main graphical Interface for the CloudAnalyst .

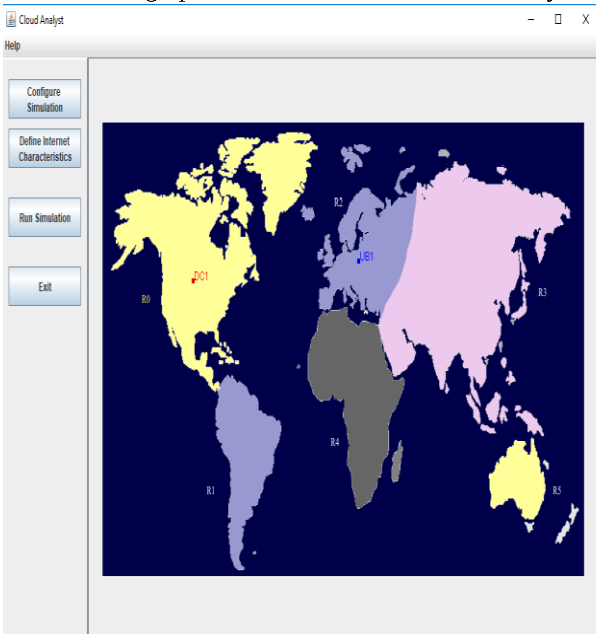

Figure 3 CloudAnalyst GUI.

The aim is to provide a convenient platform (for scheduling applications for IoT applications) that processes and analyses data issued in an effective manner. In order to improve the quality of service for these applications and to take advantage of the concept of IoT to the fullest extent, we performed a set of experiments. The aim is to substantiate the efficacy of fog computing for implementing IoT applications. This is performed by: i) executing the request at the fog computing level; ii) executing the request at the cloud computing level; iii) comparing the results (with the aim of showing the variation of delay with regard to the distance between the client and the cloud).

IV. CASE STUDIES

4.1. Cloud Network Topology

This scenario consists of only one centralized data center (the cloud server) located in North America. A cluster of nodes in the geographic region is known as the UserBase (UB) and four different UBs located across the globe are created. All the requests are carried out at the cloud server

The simulation configurations are divided into two levels: i) user base level (Table 1), and ii) advance configuration for the data centers (Table 2). All the parametric values are shown in the following subsections:

Table 1 User Bases configuration for the cloud network topology

User Base	Region	Request Per User Per hrs	Data Size Per Request (byte)	Peak hour Start (GMT)	Peak hours End (GMT)	Online user during peak hrs	Online users during off-peak hrs

UB1	1 S-America	10	100	15:00	17:00	100000	10000
UB2	2 Europe	12	100	20:00	22:00	300000	30000
UB3	3 Asia	8	100	01:00	03:00	150000	15000
UB4	4 Africa	16	100	21:00	23:00	50000	5000

In this research work, The Xen virtual machine monitor is used to monitor the virtual machine and virtualization control. The data center configuration is listed in Table 2. And Table 3 shows the physical hardware details for the data center.

Table 2 Data Center configuration for the cloud network topology

Name	Region	Arch	OS	VMM	Physical machine
DC1	0-N America	X86	Linux	Xen	50

Table 3 Physical Hardware Details At Data Center

DC	ID	Memory (MB)	Storage (MB)	Available Bandwidth	No Of Processor	Processor Speed	VM Policy
DC1	0-49	204800	1000000	100000	4	10000	Time Shared

Table 4 shows the parameters set within the simulation configuration (which includes virtual machine properties and the service broker policy), that's in order to deploy the application on the cloud.

Table 4 Application deployment configuration

Service broker policy	Data Center	NO of VM	Image Size	Memory	Band width
Optimize response time	DC1	50	10000	1000	1000

The advanced parameters for the simulation configuration listed in (Table 5).

Table 5 Advanced Configuration Parameters

User grouping factor in userbases	Request grouping factor in data center	Executable instruction length per request (Byte)	Load balancing policy across VM in Single data center	Simulation Duration
2000	1000	2000	Throttled	10(min)

4.2. Fog Network Topology

This scenario consists of one centralized data center (the cloud server) located in North America and four distributed fog data centers at every UBs regions (close to the users). Following the same idea presented in [18], the environment data is simulated into two phases: first at the fog servers and then at the cloud server. After that, the average response time in each phase was summed. In this research work, an assumption is made that exactly half of the user request will be carried out in the cloud and the rest will be processed in the fog servers. Since the two scenarios are tested on the same user bases, the configuration for the user bases is the same as in the first case study (Table 1). The only difference is that half of the user will be served at the cloud and the rest at the fog servers. Table 6 and 7 show the data centers main configuration and the physical hardware details for each data center, respectively. In this case study, 20 physical machines are used with the data center DC1 (Cloud server) and two physical machines are considered for each fog server. Table 8 shows the applications deployment configuration in each data center.

Table 6 Data Center Configuration

Type	Name	Region	Arch	OS	VMM
Data center	DC1	0-N American	X86	Linux	Xen
Fog Data Centers	DC2	1-S. America	X86	Linux	Xen
	DC3	2-Europe	X86	Linux	Xen
	DC4	3-Asia	X86	Linux	Xen
	DC5	4-Africa	X86	Linux	Xen

Table 7 Physical Hardware Details At Data Centers

Type	DC	ID	Memory (MB)	Storage (MB)	Available Bandwidth	No Of Processor	Processor Speed	VM Policy
Cloud Data center	DC1	0-29	204800	1000000	100000	8	10000	Time Shared
Fog Data Centers	DC2	0-1	102400	1000000	100000	4	10000	
	DC3	0-1	102400	1000000	100000	4	10000	
	DC4	0-1	102400	1000000	100000	4	10000	

	DC5	0-1	102400	1000000	100000	4	10000	

Table 8 Application deployment configuration

Service broker policy	Data Center	NO of VM	Image Size	Memory	Bandwidth
Optimize Response Time	DC1	20	10000	1000	1000
Closest Data Center	DC2	5	10000	512	1000
	DC3	5	10000	512	1000
	DC4	5	10000	512	1000
	DC5	5	10000	512	1000

The parameters for the simulation configuration for each data center layer are illustrated in Table 9.

Table 9Advanced Configuration Parameters

DC	User grouping factor in userbases	Request grouping factor in data center	Executable instruction length per request (Byte)	Load balancing policy across VM in Single data center	Simulation Duration
Cloud data center	2000	1000	2000	Throttled	10(min)
Fog data centers	1000	100	100	Throttled	10(min)

V. RESULTS

5.1- Cloud Network Topology

The following figures show the simulation results.

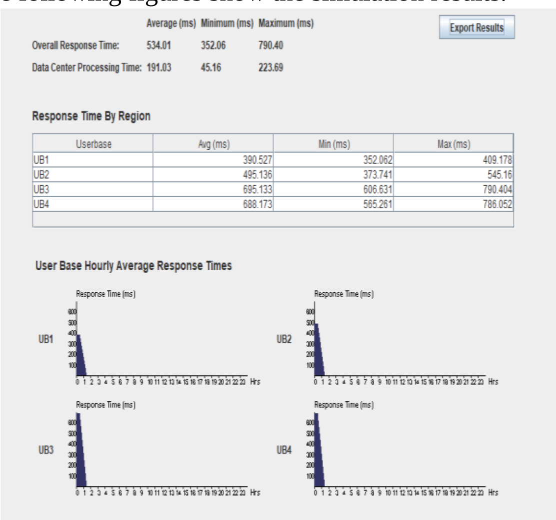

Figure 4 Response Time Result

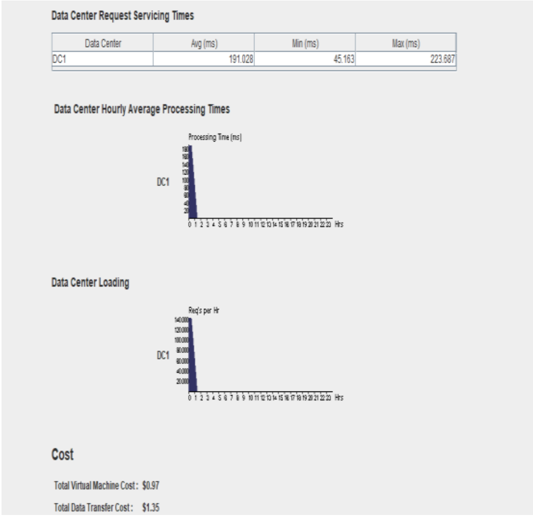

Figure 5 Data Center servicing Time and Cost Result

5.2. Fog Network Topology

The result of this scenario is divided into two phases:

5.2.1. Phase 1 (User to Fog):

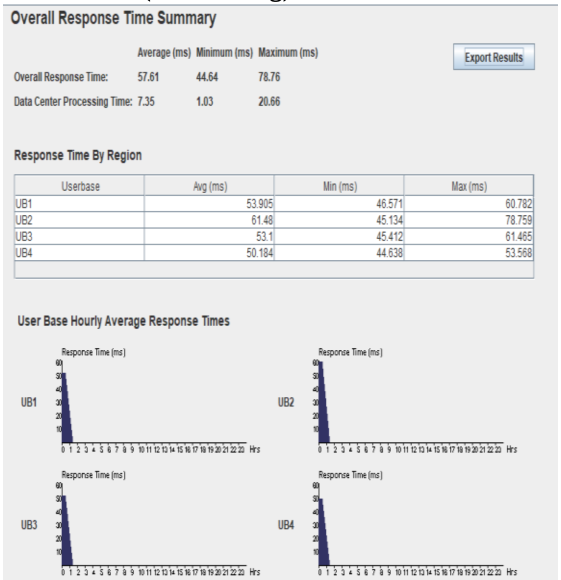

Figure 6 Case Study(2) Response Time Result Phase 1

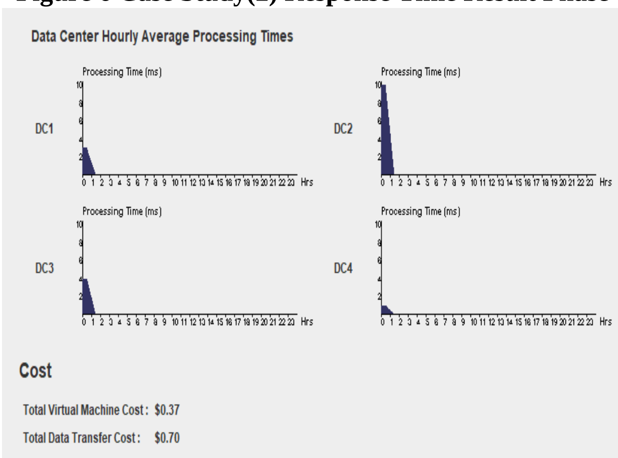

Figure 7 Case Study(2) Data Center servicing Time and Cost Result Phase 1

5.2.1.1. Phase 2 (User to Cloud):

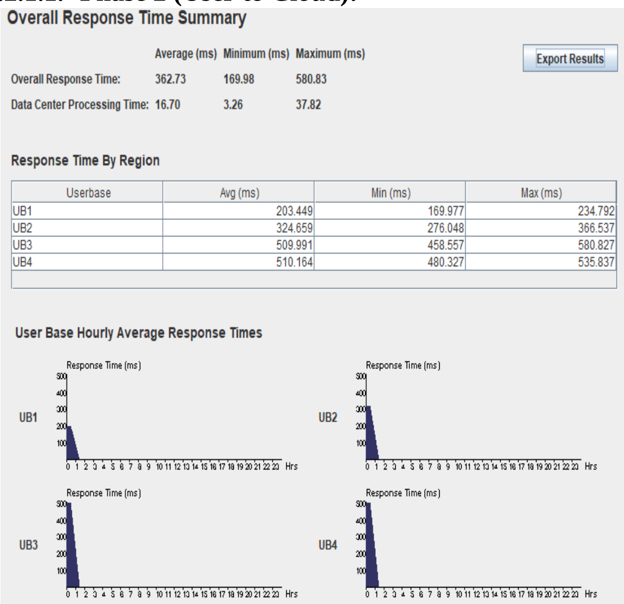

Figure 8 Case Study(2) Response Time Result Phase 2

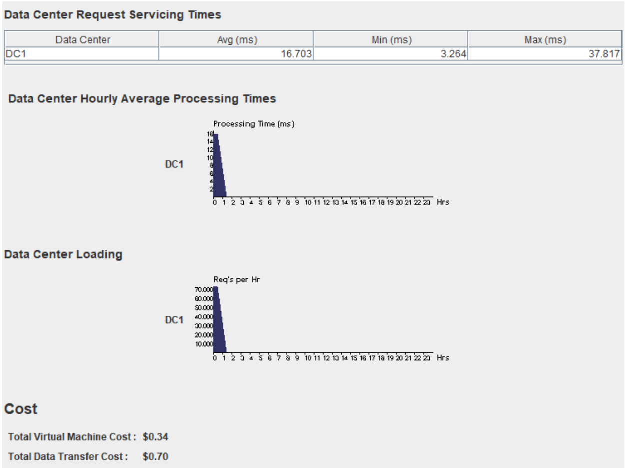

Figure 9 Case Study(2) Data Center servicing Time and Cost Result Phase 2

The results shown in Table 10 summarize the maximum response time, data center processing time maximum and total cost of virtual machine and data transfer cost between the cloud network and fog network. Figures 10, 11, 12 show comparison of these results. We can easily determine that the response time, data center processing time and the total cost of virtual machines and the cost of data transfer of fog network scenario is reduced when compared with the cloud network scenario. So the fog computing gives better results than the cloud computing in order to meet the demands of time-sensitive applications by reducing the processing time, the response time and the cost

Table 1 Comparison between the two case studies

Case Study	Processing Layer	Overall Maximum Response Time (ms)	Data Center Processing Time Maximum(ms)	Total Cost (Virtual Machine + Data Transfer ($))
1	User to Cloud	790.40	223.69	2.32
2	User to Fog	78.76	20.66	1.07
	User to Cloud	580.83	37.82	1.04
	Overall result	659.59	58.48	2.11

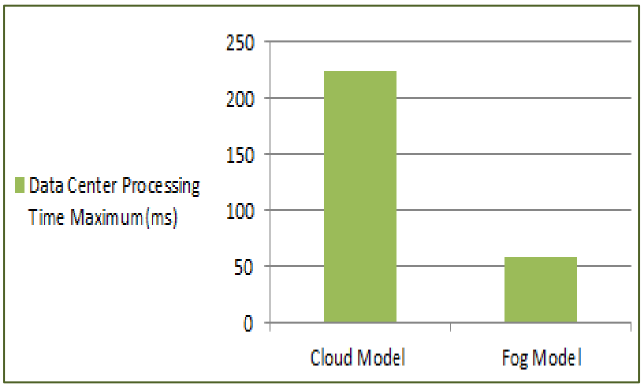

Figure 10 Results of Data Center Processing Time (ms)

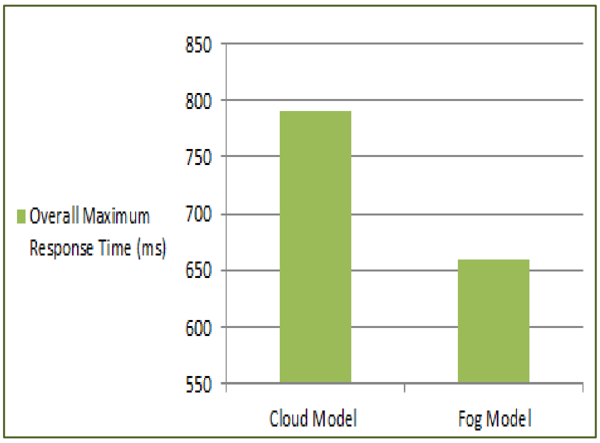

Figure 11 Results of Maximum Response Time (ms)

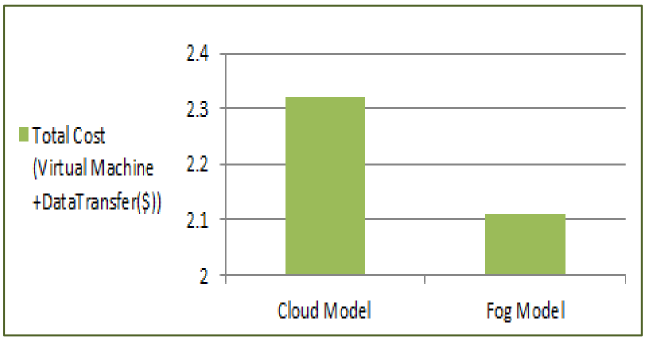

Figure 4 Results of Total Cost (Virtual Machine +Data Transfer) ($)

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VI. DISCUSSION

Depend the on experiment, a comparison was made the fog computing and the cloud computing. The data centers in the fog layer have a geographical distribution close to users, and their number is greater and their processing capacity is reduced. The cloud data centers are located in geographic locations far from users and have stronger processing capabilities which result raise in the response time and cost of data transfer at cloud computing.

A- Response Time and processing time :

Based on the experiments, we note the fog computing have less the response time and processing time than the response time and processing time of the cloud computing Because the data centers in the fog are close to the users. And a number of server at the fog computing is more than cloud computing.

B-Cost:

As noted in the experiments, the cost of data transfer in fog is better than the cloud. This is due to the proximity between the data sent by customers and the data center in the fog. Also, the cost of virtual machines in the fog less than the cloud back is fewer specifications and weaker than virtual machines in the fog over the cloud.

VII. CONCLUSION

These days, as the number of IoT devices are increasing, thus producing a high amount of data, there is a stringent needed for fast and efficient processing. Fog computing is an emerging solution to this problem of data processing that comes with its own advantages and disadvantages.

Based on our detailed experiments and discussions, we can conclude that fog computing paradigm always performs better than the traditional cloud computing model to meet the demands of time-sensitive applications by reducing the delay and response time.

FUTURE WORK

The research focuses on the comparison between the fog and cloud computing according to their latency. There are seven other criteria we can use them in the comparison such as capacity, bandwidth, security, speed ,and data integration. In the future, we can simulate these two models of computing depending on one of these five criteria. Also, in the future, an algorithm for distributing the load between the data center and the fog devices can be implemented to simulate any network topology that has fog devices.

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