# Mist computing Framework for Delay Sensitive Medical Applications


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# Approval

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# Table of Contents

## List of Figures

## List of Tables

## List of Abbreviations

| | |
|---|---|
| **IoT** | Internet of Things |
| **IoMT** | Internet of Medical Things |
| **M2M** | Machine to Machine |
| **E-Governance** | Electronic Governance |
| **RFID** | Radio Frequency Identification |
| **EMR** | Electronic Medical Record |
| **WBLC** | Wireless building lighting control |
| **API** | Application Programming Interface |
| **IoTHeF** | Internet of Things in Healthcare Framework |
| **IaaS** | Infrastructure as s Service |
| **HaaS** | Hardware as a Service |
| **SaaS** | Software as a Service |
| **MaaS** | Middleware as a Service |
| **PaaS** | Platform as a Service |
| **APPA** | Anonymous and Privacy Reserving Data Aggregation Scheme |
| **FN** | Fog Node |
| **PCS** | Public Cloud Server |
| **LCA** | Local Certification Authority |
| **SD** | Smart Device |
| **SPF** | Sieve, Process and Forward |
| **E-HMAC** | Emergency Help Alert and Mobile Cloud |
| **ECG** | Electrocardiography |
| **EMG** | Electromyography |
| **IoHT** | Internet of Health Things |

## Abstract

Cloud Computing made possible to manage large storage, thereby providing improved processing by utilizing virtual processors. As technology is progressing, researchers and industries are coming together to built smart technologies to automate activities performed or managed by human beings. Since, the advent of IoT has made communication possible between things, automation has reached new heights. IoT along with cloud technology is made applicable to number of areas for automation of functions carried out in these areas. Cloud being distant from the application layer, results in slow processing. The challenge was mitigated by Fog computing to some extent. IoT based applications designed for Healthcare are life critical and cannot afford slow processing specially in applications where late decision making might cause death of patient. Therefore, this research mainly targets the IoT in healthcare sector and as a result of research, latency is found being the main hindrance in applying IoT in delay sensitive medical applications. Moreover, a thorough research is carried out on fog computing in healthcare and IoMT framework application. This research addresses and resolves the problem of latency in delay sensitive medical applications. To address the issue of latency, Mist framework for delay sensitive applications is proposed which makes the use of mist nodes for better latency, network usage and execution time. Using Ifogsim simulator, comparison between cloud and proposed Mist infrastructure is performed. It can be observed in the results that introducing Mist nodes between cloud and application layer has expediated the processing process which is necessary in healthcare services to save lives of humans.

**Keywords: [Cloud Computing, IoT, IoMT, Mist computing]**

# Chapter 1

# 1. Introduction

## 1.1 Overview

Health is one of the primary factors which plays a pivotal role in establishing the economy of a country. A good health infrastructure proves as a backbone in the development of a country. The economic equilibrium is disturbed if the productivity at work is damaged as a result of poor health. The government of state has the responsibility of providing best available healthcare facility to its people. There are many initiatives that are been taken up by the governments so that modern technology is incorporated in healthcare service of the country. Better health of citizen lead to better efficiency of citizens [1]. The United Declaration of Human Rights which was presented in 1948, states in Article 25 that all humans have the right to public health and medical care [2]. In the article 35 of European Union (EU) Charter of Fundamental Rights, it declares that every citizen should have access to highest standard of healthcare and to benefit from the available medical facilities, human life would be of high value and measures would be taken to safeguard it [3]

Huge amount of development in the field of wireless sensor networks and telecom has resulted in innovation in many walks of daily life. This has led to many devices being connected and forming a large network called Internet of Things (IoT) which is the future of internet [4]

Internet of Things (IoT) plays a major role in enhancing the living standards by improving the provision of health care services to the highest level. It is estimated by Ericson that almost 2 billion devices will be connected to one another by the end of this year. It is also estimated that machine-to-machine (M2M) communication will be made available in 15billion devices. The ratio of devices per person has already crossed to 6-7 each. Due to such large network of communication, the volume of data per area would increase by 1000 folds [5]

The range of application of IoT can spread over many sectors which include manufacturing industry, transport industry, retail, event handling, tourism industry, energy sector, healthcare, logistics, environmental systems, and agriculture. These sectors have been revolutionized by the introduction of Internet of Things (IoT). The daily operation can be streamlined effectively using the IoT [6].

In the top 10 application areas of cloud, healthcare stood 5$^{th}$ in the last year, 2020. There is a continuous rise in demand of Internet of Things health applications with each passing day. These applications include medical record keeping, telehealth services, remote diagnostics, and robotic arms. [7]

Healthcare industry has gone from 1.0 to 4.0 generation. Healthcare 1.0 had very limited resources. Healthcare 2.0 was made possible due to sophisticated medical imaging by use of technology. Healthcare 3.0 was centralized in nature where patients were dependent on hospitals for their treatments. With the recent development in technology such as cloud and fog, healthcare 4.0 has been made possible which has reduced the expenditure on the patients. This has reduced the burden on economy for providing the basic health facilities which is the right of every human being. [8]

The biggest economic impulse will be created by manufacturing and healthcare application in the coming years. All type of healthcare applications which are based on IoT infrastructure will be creating a whopping amount of 1.1 to 1.25 trillion dollars in the annual growth by the global economy in the span of five years from now. These types of stats pave way for high end businesses and entrepreneurs to invest in the sector of healthcare and to not miss on the new opportunity that is available now. Top businesses such as Bsquare, Net4things, Flexera, Samsung, Pubnub and Solair are already working hard to make solutions for healthcare provisioning based on the Internet of Medical Things (IoMT).

The success and working of Internet of Things depends heavily on the cloud infrastructure. Cloud computing is the technology that can fulfill the needs of Internet of Things (IoT). It can provide unlimited resources to the IoT infrastructure. Large amount of data produced by IoT is processed by the unlimited processing cores that are provided in cloud infrastructure. The large amount of medical data will be processed in theses cores. Unlimited amount of data that is produces need to be saved for future reference which is stored in the abundant storage provided by the cloud infrastructure. To use these services, a good internet connection is the foremost requirement. [9]

There are some drawbacks associated with cloud which needs to be taken care of if implementing cloud for healthcare service. The sending of medical data, processing and receiving the required action takes a long time in cloud infrastructure deployment. The medical applications cannot afford this delay as it can cost a precious life. This delay in cloud infrastructure is not feasible for medical applications that are using IoT for its functioning. The medical IoT applications would need local processing of data at the edge of network so that delay time is minimized. [10]

The best features of Internet of Things, Wireless sensor networks and Cloud Computing have been combined to introduce a new computing paradigm which is called Fog Computing. Fog Computing is most suitable for applications that are time sensitive, location aware and context aware. This is made possible by using processing resources for processing in the near location of data producers. The data that is processed locally do not have to go to cloud using the bandwidth of the network [11]

Large amount of data is produced by internet of medical things (IoMT) which is implementation of IOT in medical sector. The rate of growth of data is exponential in nature. This large amount of data that is produced is used in carrying out analytics as well as predictive data processing. The fog computing takes the functionality of cloud and mirrors it to close neighborhood of data producers. This close deployment helps in local processing of some data which could be beneficial for latency sensitive application like healthcare services application while the remaining amount of data can go to cloud for processing and takes its due time for processing. Fog computing also has some demerits as its deployment need end devices to have capability of processing. [12]

## 1.2 Problem Statement

Cloud computing has served as the best infrastructure for deployment of Internet of Things (IoT) which is a steppingstone for smart cites to become a reality. The IoT is also being replicated in health sector which takes the form of Internet of Medical Things (IoMT). Tech savvy wearable and sensors have played a great role in development of Internet of Medical Things (IoMT). They provide data which makes it possible for remote healthcare and treatment to take place. The remote healthcare has made the health facilities to reach the remotest of the areas. The burden on health infrastructure can also be reduced. The data is collected by the edge nodes and sent to the centralized location of cloud for processing. The transfer of data from edge to cloud is time consuming. The data is processed in the cloud and an action is sent from the cloud, based on data that is processed there. The processed data reaches the edge so that actuator can perform the necessary action that is expected after processing of data. This whole process is time consuming and energy is wasted. Such long response time is not feasible for healthcare provisioning apps which need rapid response. The long response in case of cloud can result in a loss of an important life. This drawback associated with cloud computing makes this infrastructure not the best fit in case of healthcare applications which are built in order to provide best health facilities and to save lives of human beings.

## 1.3 Proposed Solution

The process of sending, processing, and receiving is time consuming. The process can be expedited by introduction of mist layer near the edge of network. This induction of mist layer will help medical application to carry out their operation efficiently by reducing the latency. This mist layer is incorporated in between the generation point (device) and storage point (storage). In this research, we propose a framework called Mist computing framework to cope with large response times in case of cloud-based processing and storage. Minimum response time is needed by remote health provisioning services. The framework has mist nodes which are small clouds which have taken some functionality if cloud. They are set close to the data generation point and can carry out necessary operation locally without the need of sending the data to the cloud and then waiting for the response to reach back. The mist nodes will carry the processing function very fast as the transmission delay is more than processing delay. This will help the medical applications to works efficiently in emergency situations and save valuable lives. The tasks that need immediate attention would be processed locally and the tasks that are not urgent would be sent to the cloud to take its due time for processing. This will revolutionize the health industry as health services are provided at home due to mist computing without the need of travelling long distances to get proper treatments.

This will greatly reduce the burden of health infrastructure of the country which can collapse in case of a pandemic when more and more people come to visits hospitals compromising the limited resources available to provide medical assistance. Better medical services would lead to a better life expectance in the country.

## 1.4 Thesis Motivation

The concept of smart cities has strong roots in Internet of Things (IoT) due to which its realization is becoming a reality. The smart hospital is also subset of smart cities which is based on internet of medical things. The IoT depends on cloud technology to fully utilize its potential. The cloud computing paradigm has few shortcomings due to which it is not best suitable for medical application which are part of smart hospitals concept. The medical applications require minimum latency for its best possible functionality as life of a human depends on it. If the delay caused by cloud computing is not solved, then the IoT is not viable for health sector. The motivation behind this research was to solve this problem of latency and energy consumption by introducing mist nodes between the cloud and end nodes with the purpose that it would process most of the data at the close neighborhood of data producing sites before sending aggregated data to the cloud. This would decrease the latency as well as the energy consumption.

## 1.5 Thesis contribution

This framework will help in streamlining the process of medical health provision to the general public in a state of art architecture. This will be a step towards practical realization of IoMT where medical appliances are connected to other devices giving the best medical services without much load on medical infrastructure of the country.

## 1.6 Related Industry

The direct relation of this thesis will be with the health industry and technology industry. Newer and better application would be developed once the latency issue is solved in providing IoT based medical care services. This work can also be used in vehicular industry, manufacturing industry, agriculture industry and many more such industries which require rapid response when deploying IoT based applications.

## 1.7 Thesis Research Methodology

The approach that is adopted in piece of research is of hybrid nature. This research consists of conceptual, applied and fundamental. The details of roadmap which was are taken when conducting this research is presented as under.

- Domain of research is specified
- Related Literature Review is carried out
- Critical Analysis is performed
- A research topic is targeted
- A specific problem is pointed
- Formulation of a Hypothesis
- Observations
- Finding of a solution
- Experimentation or Simulation
- Presentation of results

## 1.8 Thesis Organization

The organization of the thesis is represented in figure 1

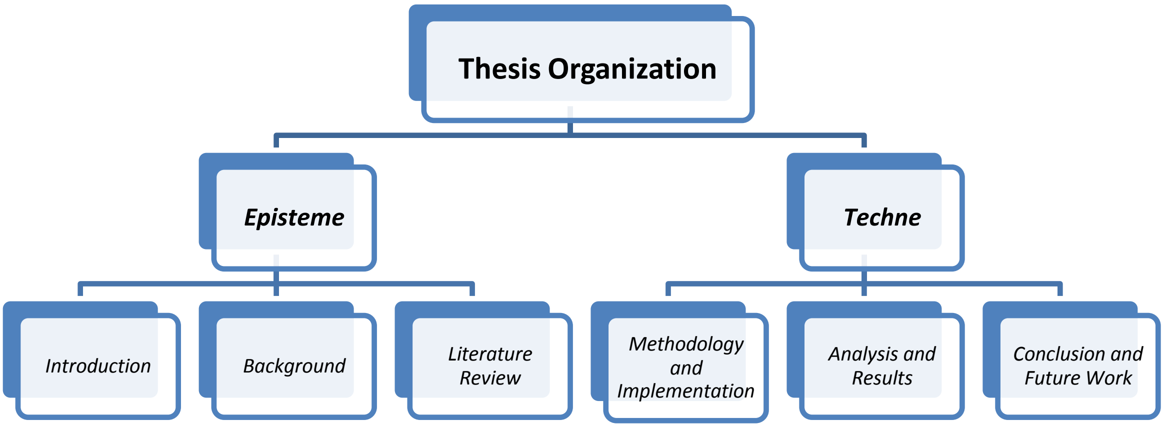


**Figure 1: Thesis Organization**

Remainder of thesis is organized as follows:

### *1.8.1 Chapter 2: Background*

In chapter 2, we will basically explain the technologies that are used in the research from background perspective. It gives insight on how these technologies were developed and how do they contribute to making IoT based health services possible.

### *1.8.2 Chapter 3: Literature Review*

This chapter basically is concerned with all the previous techniques to deal with latency in IoMT devices and how the Mist Computing has been used before in healthcare industry in terms of solving the issues in its operations. It will also discuss some of the papers which have suggested Mist based solutions for rapid processing of data.

### *1.8.3 Chapter 4: Implementation*

In this chapter, it is portrayed how the proposed methodology will solve the issue of latency in case in cloud based IoT solutions. It is proved how mist nodes help in processing of data near the generation point of data. Complete implementation of the application is explained in this chapter.

### *1.8.4 Chapter 5: Analysis and Results*

This chapter is dedicated to the explanation and to give demo of the functionality and results of the proposed simulation and how it works efficiently as compared to the cloud in other cases.

### *1.8.5 Chapter 6: Conclusion and Future Work*

In this section, conclusions are drawn about the framework and what has been achieved using the mist nodes in the research conducted. Secondly, future prospects are discussed that can add to the functionality of mist nodes.

## 1.9 Summary

This chapter has the explanation of basic terminologies which are related to this research. It provides brief introduction to the technologies that are used. The terms related to the Internet of things, cloud computing, fog computing and mist computing are given an overview. The main aim and scope of the thesis is provided. The objective which it fulfills is also explained. This chapter has also put out the layout of the thesis which will be followed in next chapters.

# Chapter 2

# 2. Background

## 2.1 Introduction

Since technology has paved its way in human life, it has continuously evolved to make human lives easier. Invention of computer made the computation tasks easier and storing information became easier and easily accessible. The storage for information later got organized bringing the concept of database which serves the purpose of analysis. Human got to interact with computer and communication between human and computer was built [13]. Use of technology to build communication was made possible with networking. On a small scale, computers were connected with each other to communicate for certain tasks. Later, Internet was introduced which provided the computer devices to connect with the worldwide network called as Internet. Initially, the internet used cables for connection [14]. Later, wireless technologies were introduced, and cellular devices were invented which provided communication wirelessly. Technology progressed and a wireless internet connection was introduced in computer devices as Wi-Fi and in mobile phones as Wi-Fi and 3G [15]. This technology improved and smart phone technology is now ruling the world with multiple activities running on a single smart phone device. Deploying online applications need huge storage and fast processing to provide desired efficiency. This problem was solved by cloud technology [16]. With the advent of wireless internet, communication between systems came into being. Initially, computer systems used to communicate under certain network. Using internet, the computers communicated with devices located worldwide. This improvement in technology made it possible for various things associated with sensors to communicate with each other without human-interaction. Things connected with internet are made part of certain network that serves the purpose of performing some function. This phenomenon is called as IoT [17]. IoT can be fully utilized when used with cloud architecture. As this technology gained popularity in applications just like, autonomous vehicles, home automation, smart cities etcetera, the need for fast processing and storage elevated. As it was mentioned earlier that IoT is nearly impossible without cloud due to large volume of data being produced by end devices but still as the number of applications based on IoT grew, the required processing and storage was not fulfilled by cloud. Hence, causing, latency and high-power usage in IoT systems. In order to mitigate the challenge of latency, Fog layer was introduced by Cisco with some other co-researchers [18]. In this chapter, Cloud computing, Fog Computing and their basic architecture will be discussed. Furthermore, IoT and applications of IoT in various areas will also be discussed. The chapter mainly gives overview of how Internet technology grew and usage of cloud and Fog-computing to facilitate IoT based Systems.

## 2.2 Basic Architecture of Cloud Computing

Cloud is defined as a pool where on-demand network access is made available to set of hardware and software devices such as networks, storage, servers, applications and services [19].

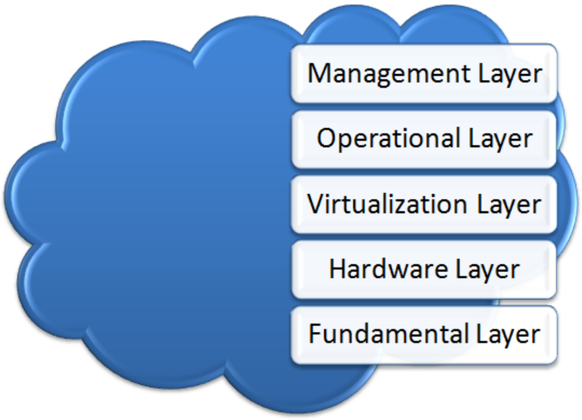


**Figure 2: Basic Architecture of Cloud**

This architecture of cloud as shown in figure: 2, serves the benefit of availability and adaptability with complexity being the major disadvantage to this architecture. This cloud architecture being complex makes it tough to work with large number of components as taking the risk of complexity can affect all of the components and results failure of the system as a whole when it comes to performance. This makes the cloud technology very expensive to be used. Moreover, benefits of using cloud technology cannot be denied. It makes it possible to process and store large volumes of data with efficiency and cost effective than local storage. Cloud architecture is based on several layers which are explained as under:

### *2.2.1 Fundamental Layer*

It is basic layer of the cloud which is allocated for energy management. It has energy converters, energy intermediaries, energy storage and other components such as cooling water, air-conditioning, natural hazards protection tools and many other required tools for energy management.

### *2.2.2 Hardware Layer*

This layer is basically used to convert mechanical resources into physical IT resources which then benefit the virtualization layer. It acts as a mediator between fundamental and virtualization layer. This layer contains physical networks devices, physical servers, physical data storage devices and other supporting components.

### *2.2.3 Operational Layer*

This layer is responsible for maintaining continuous operations and its sustainability depends on other layers. This layer has database management, application for processing, network applications, virtualization tools and other components.

### *2.2.4 Virtualization Layer*

This layer serves as mediator between hardware layer and operational layer by utilizing the hardware resources just like virtual storage, networks or resource centers and provides services to operational layer.

### *2.2.5 Management Layer*

Management layer being the top layer of the cloud architecture has management tools as its components. The layer directly deals with operational layer but is indirectly connected with other layers in terms of its sustainability and continuous availability [20].

The infrastructure of computers has grown from basic integrated to converged infrastructure over past duration of time. The converged infrastructure known as cloud computing is used to meet the varying demands that are put forward by the costumer. The demands are met dynamically in the runtime. The distributed nature of cloud computing has many virtual machines as an integral part [21].

## 2.3 Types of Services in Cloud

Cloud computing provide different types of service that can fulfill different requirements of users. There are three types of service models that are provided by cloud.

### *2.3.1 Infrastructure as a Service (IaaS)*

IaaS is the primary service that has been provided by the cloud. This service is the main reason for success of cloud computing, the hardware and infrastructure are made available for compute and storage purpose. The reason stated above also makes it hardware as a Service (HaaS). It provides abstraction to the user by managing the computing, storage, network scaling and security. The payment method is pay as you go according to the usage of resources.

### *2.3.2 Platform as a Service (PaaS)*

It is also termed as Middleware as a Service (MaaS). The developers are provided with platform for the development of applications. The standards that are to be followed by developers are provided by the vendor. The developer just has to develop application without getting into trouble of purchasing and licenses and other managerial affairs. It is the job of the vendor to look at these details.

### *2.3.3 Software as a Service (SaaS)*

The end products are provided to the users as a service. The end user has to just use the application without looking into the pre requites requirements which are fulfilled by the vendor. Installation and management of the application is responsibility of vendor. There is only single access point for the users. Updates are better managed because if centralization. The costs are reduced as operational maintenance support cost is waived off the users [22].

## 2.4 Adoption of Cloud solutions and Existing Cloud Computing Models

Adopting cloud solution is very complex task and requires thorough research before adopting one. The choice is made keeping in mind several dimensions that could affect the system as a whole and proper utilization of resources is determined. The choice majorly depends on allocated budget for adopting cloud solution. Adopted cloud solution must be cost effective as compared to investing on an additional IT infrastructure. Different cloud providers provide different services and capacity of cloud in terms of operations depends on standards they use. Adopting a cloud computing model form cloud providers is quite a difficult job as it provides the control of internal data to cloud-providers. Keeping in mind, the requirements of organizations, different cloud models in terms of privacy are provided by vendors which are discussed as under:

### *2.4.1 Private Cloud*

Private cloud is allocated to only one organization so that information a cloud retains, is kept private. Units within this organization or department may use services of this cloud. A company might choose to build its own cloud or buy services from cloud providers. Cloud can be adopted on-site or off-site depending on the needs and nature of services of an organization. Cloud services are provided making the use of intranet. This guarantees the security. Migration of data while deploying cloud solutions and its maintenance has high costs.

### *2.4.2 Public Cloud*

Public cloud provided by cloud providers comes with control over infrastructure to providers. The installation of infrastructure is performed on-site. Agreement is done in terms of payment for using the services of the cloud between organization and cloud solution providers. The pricing depends on services you choose to use from the cloud. The services can be used using internet through browser. Public cloud is less complex and more reliable than private cloud but not secure enough and flexible in terms of features.

### *2.4.3 Community Cloud*

A community cloud is built keeping in mind the same nature and needs of some organizations. These organizations build a cloud on sharing basis and its resources are shared among them. This type of cloud is built and implemented by universities and some of the banks [23].

### *2.4.4 Multi-Cloud*

Multi Cloud uses multiple resources that are provided by different data centers of a provider. Later, multi-cloud was made by leveraging resources from various providers. It was difficult to use manage applications using resources provided by providers. For common APIs, it was necessary that they incorporate different types of resources available by providers. Resource providers are added to the cloud market very rapidly and therefore it is not an easy task to have all of them incorporated in commonly used APIs. The list for available resources by all providers is not specific and varies over time. Also, billing methods and prices for each provider are different. There is no common catalogue which describes complete set of resources that will be available on the cloud. Each provider has different models for the services one buys. Therefore, it becomes very tough for programmers to develop the application for desired combination of multi-cloud that utilizes the resources made available at their best. In multi-cloud application, one has to manually program the application due to lack of common APIs build for the multi-cloud architecture. Depending on the needs of application, providers and resources are chosen and application is built accordingly keeping in mind load balancing, managing each resource at its best, fault tolerance as there exists no unified platform that makes it possible otherwise. Some of the APIs have been developed to mitigate these challenges to some extent such as jClouds and Libcloud but adopting multi-cloud by various providers still requires more research to get the better results. Multi-cloud is further divided into two categories discussed as under:

#### *2.4.4.1 Hybrid Cloud*

Hybrid Cloud is a type of multi-cloud which is combination of private and public clouds or can have a public and private combined IT infrastructure. Hybrid cloud is basically used to store sensitive data. Healthcare departments and Energy sector have adopted Hybrid-clouds to deal with sensitivity of information generated and stored on the cloud. Hybrid-cloud has challenges in terms of setting up a network. In order to access public cloud from private cloud, network topologies, latency and bandwidth are taken into account. To make this infrastructure more effective, networking is performed between public and private clouds. This in effect results in extra management of private resources which is a tough job to handle.

#### *2.4.4.2 Federated Cloud*

Federated Cloud is also type of multi-cloud which provides portability feature to the applications by combining various cloud providers into one. This allows the users to move data from one cloud to another thereby mitigating the challenge of lock-in vendor condition. It is not an easy task as there are network problems, abstraction in layers, types of resources provided. Also, cost to migrate huge amount of data from one cloud to another is set according to volume of data to be migrated. Small scale providers may be more comfortable to extend their resources but large-scale providers will not be willing enough for that. The reason for this appears to be the spread of resources over the globe [24].

## 2.5 Benefits of Using Cloud

The benefits of using cloud computing solution are described as under:

### *2.5.1 Cost Effective*

Adopting cloud computing solution is quite budget friendly as organizations only pay for the services and does not have to maintain complex hardware and software infrastructures. Cloud providers have made payment methods quite flexible in terms of pricing and one can purchase depending on needs of organization just like one-time or pay-as-you-use.

### *2.5.2 Storage*

Cloud makes it possible to store and manage huge volume of data efficiently.

### *2.5.3 Accessibility*

Cloud can be accessed remotely which makes it easier to use its services by connecting through internet. Data in cloud is centralized and can be accessed by its authorized users only ensuring the security of data.

### *2.5.4 Deployment*

Implementing cloud solutions take lesser time than building whole infrastructure on your own.

### *2.5.5 Backup or Recovery*

Centralized storage provided by cloud makes it possible to maintain back up of the data which can be recovered easily in case of loss or damage. Therefore, during the process of recovery of data, operations at the customer end are not affected.

### *2.5.6 Scalability*

Cloud providers have various varieties of services depending on needs of organizations which make it easier for its users to pay only for the required services.

### *2.5.7 Better Integration*

Clouds make it easier to be integrated with the existing system without requiring any alteration in existing software [25].

## 2.6 Fog Computing

As cloud computing is centralized architecture to provide facility of accessing remote resources, fog computing being extension of cloud computing is decentralized architecture which provides the same facility at faster processing rates. The main idea of fog computing was introduced by Cisco along with Microsoft, Dell to maximize the effectiveness of real-time interactions required in IoT. Fog computing makes the use of edge computing and acts as a layer between network and application layer. This layer basically processes the data generated by application or hardware layer. Cloud being the ultimate destination of data and edge of the network is initiating point of data where data is generated. Fog computing combines them both into one layer to decrease he response time. Fog computing is slightly different from edge computing as edge computing can use edge layer or gateway to process data whereas fog computing on the other hand only uses gateway to process data and return the results after sending them to various sources available to the fog layer [26]. Huge amount of data generated in IoT can be computed using Fog computing. Fog computing makes it possible to lower the latency in sensitive applications where delayed results can affect critical lives. To prove this, mathematical analytics were performed considering consumption of energy and latency rates. The results of fog computing architecture were compared with that of cloud architecture and resulted in 40 percent decrease in consumption of energy. Also, latency rate was lowered as compared to the results of cloud-computing [27].

# Chapter 3

# 3. Literature Review

This chapter discusses the related work that is carried out by the researchers of the field. It has also examination of basic terminologies and technologies that are used. The related work is the work that is similar to the work carried out in this thesis and it contribute in developing a new solution.

The literature review is divided into section for ease of understanding. The first part discusses cloud computing in healthcare and smart devices which made Internet of Things (IoT) possible. The second part includes the fog computing and edge computing technologies that have been adopted in healthcare services. The last part discusses about the IFogSim simulator that is used to simulate the research work in this thesis.

## 3.1 Cloud Computing in Healthcare

Smart wearables are high tech wearables which are becoming integral part of our lives. Internet of Things (IoT) infrastructure is built based on the smart wearables. These wearables gather important data, process it and make a calculated response. They are finding use in four major domains: (1) Health, (2) Sports, (3) Tracking and localization, and (4) Safety. IoT enabled wearables are basically smart wearables which can be used as implants in the body, or external accessory, in garments, or as ingestible or tattooed in the skin. The evolution of technology is paving way for newer and specialized smart wearables. The wearables have gained access to the internet due to which it can send observed data and receive the commands as responses. This has also made possible to have interactions and communications with the other devices as well. As the technology is improving, the size of electronic devices has reduced, and processing capabilities have improved. Smart watches, eyeglasses, smart ear buds, smart jewelry and wrist bands are used in different applications. The most important applications of smart devices are in medical field. The applications that the smart wearables are finding in the medical field range from monitoring of patients remotely to treatment and from tele services to rehabilitation services. The sensors are capable of sending important bio data over the internet or may receive data so that the user can make decisions based on that data. The IoT rehab devices can make life of physically challenged patients much better. Health monitoring devices can be classified in four categories: Bio-potential, biochemical, environmental and motion sensors. The wearable devices can also be divided into vital signs monitoring and non-vital sign monitoring. Vitals sign monitoring include pulse, respiration value and body temperature while non vital signs monitoring include blood pressure and blood oxygen. Potential stroke patients can be helped using IoT armbands. Smart wheelchair can help disabled person. Heartbeat can be measured and monitored by smart wearable on wrist or chest. This can help in avoiding the cardiac arrests. These devices can be used to measure temperature of body. Easy to wear smart devices help in constant monitoring of blood pressure. Wrist-wearable pulse oximeter is used to measure the oxygen level in the blood. The blood level is used check the saturation level of oxygen using PPG signals. These smart wearables have made it possible for a well-coordinated effort of devices to improve the standards of living [28].

Internet of Things is rapidly growing since its advent as it provides the automation of processes that were performed manually previously. Devices are connected with internet and sensors are attached with them which generate large volumes of data. Storing this data with standard security protocols requires huge storage which is made possible with cloud computing. IoT has number of applications which include smart homes, traffic control, automation of industrial plants and healthcare. Healthcare is one of the sensitive application domains of IoT which not only requires secure environments but quick processing as well in order to give desired results in less amount of time. Healthcare being a life critical application cannot afford delayed responses generated in medical applications. Real-time medical applications built with Internet of Things technology allows the facility of acquiring data from patients remotely and provide it to caregivers. Sensors have been developed which can measure patient's vitals at single touch. These sensors are incorporated in IoT network and communication is built to use this data from sensors in application. Healthcare application developed with IoT has a lot of challenges to face such as: exchanging data between devices, storing data, managing data securing data and providing unified access to resources. The possible solution to mitigate this challenge was primarily made possible with cloud computing. IoTHeF is the basic framework proposed for healthcare applications based on IoT. This framework provides the facility of utilizing IoT at its maximum potential using cloud computing [29].

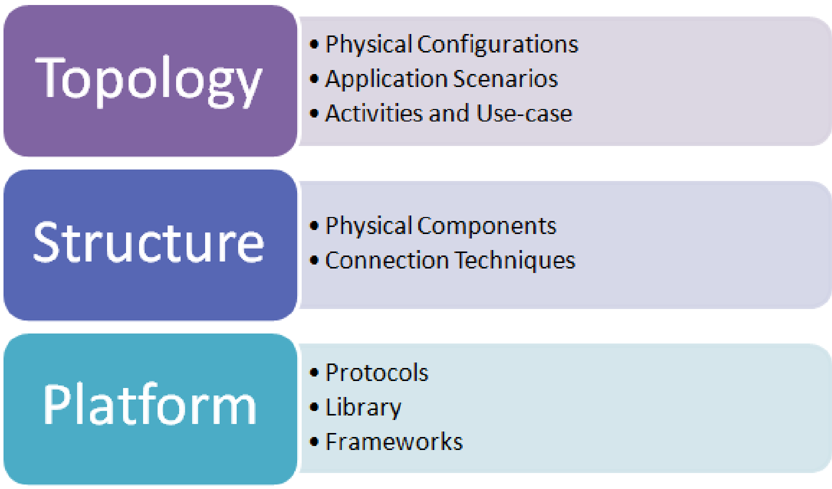


**Figure 3: Fundamental Elements of IoT with main Functions**

Cloud makes it possible to access several resources by virtualization. These resources can be remotely accessed worldwide through internet. The goal of cloud computing technology is to facilitate human beings and solve complex problems into simplest ways possible. Mobile phones being part of daily life of human beings are currently used to perform many activities. MCCEH is a model proposed to deal with medical emergencies using mobile phones. This model provides the quick response time by using cloud technology thereby maximizing the chance of saving lives at emergency. The model has video streaming feature to guide the patient initially and diagnose the problem so that proper treatment and hospital can be chosen. This saves the time of patient by not physically visiting multiple hospital to get required emergency care as availability of emergency services is not guaranteed by each hospital at the same time [30].

A model of hospital developed on IoT was proposed which gives detailed description of smart hospital that provides the benefit of E-governance as well. The model is based on combination of telemedicine and IoT technology to better provide the controlled healthcare facility. RFID is suggested to be used to store and transfer data. Several devices will use RFID so that they can be uniquely identified. Electronic Medical Record (EMR) and RFID are combined together to provide security to the data so that analysis can be performed. Cloud Computing servers, wearable devices and sensors are used to generate and process data required for medical procedures. IoT based medical system would alert the medical staff based on the data collected through sensors. Doctor can remotely treat the patient using the vitals received through sensors and sent to the doctor via application. This model automates all types of management done in hospitals including environment management, Garbage management, water management, smart wheelchairs, Telemedicine Ambulance, RFID technology and WBLC. All of them are connected with internet to build communication. Physicians and other medical staff can monitor the patient using the data collected through sensors and other technologies used. The model is designed in a way which alerts the doctors when patient's health is at stake. The model focuses more on IoT architecture but it is quite obvious that implementing this model will require abundant resources to process the data generated by smart devices [31].

## 3.2 Edge and Fog Computing in Healthcare

Medical applications are being developed using IoT and smart sensors to improve the automation of hospitals and giving customer satisfaction. In medical applications, the sensors generate huge amount of heterogeneous data which needs to be filtered in a way that maximizes the potential of IoT infrastructure. This data needs to be processed in an efficient manner which sends the information to targeted systems. Healthcare applications using IoT encounter huge amount of data sent over the network for processing. In order to deal with this problem, remote server must be used for data transfer, pre-processing should be done by the system or edge computing must be performed. Machine Learning has evolved since Deep Learning was introduced. Deep learning provides the advantage of data abstraction. Deep learning eliminates the extra task of extracting features. The degree of accuracy achieved by deep learning has improved overtime. The higher accuracy rates are achievable with heavy computational which is a drawback to deep learning to be applied to healthcare applications. Deep learning architecture that provides less computational costs have regularization problem. Therefore, it makes it difficult to use deep learning models in some of the applications which require both, i.e. the balance between accuracy and less computational costs. Deep Learning follows sequential patterns which slow down the processing capacity of the system thereby curbing parallel processing. For IoT to work, connectivity and communication among devices and systems and data generated by the devices, which are sensors in case of smart medical applications needs to be communicated wirelessly with the system. Some kind of data can be sent wirelessly such as electroencephalogram while others such as blood tests cannot be sent wirelessly. To make the computation effective, deep learning model was proposed to detect pathological parameters. Pathology is the first step of any medical procedure and its accuracy is highly important for systems that deal with healthcare. In this model, pathology is done using EEG headset. This model has tree-based structure and provides accurate results [32].

In this paper, the authors discuss the context-sensitivity about the data that is produced when fog computing is used for patients that have chronic ailments. The large amount of data that is produced in IoT is not enough for better treatment of patients but data that is relevant to the patient that can help in cure of patient. The fog computing helps is sending reduced amount of data on the network. The context aware architecture that is proposed in the paper will help in providing personalized care to the patients. Context can have two perspectives which are intrinsic context and extrinsic context. The extrinsic context deals with the surrounding parameters that can affect the health patients. The intrinsic context will have data that is collected from sensors attached to the body of the patients. Both contexts provide detailed readings that can affect the patient adversely. The data that is not relevant to the patient is filtered so that unnecessary data is used [33].

Healthcare industry is still young as it began in 1970 with healthcare 1.0 having basic resources. The healthcare 2.0 was made possible through the technical improvement in imagery in the medical field. The development of IT infrastructure and its adoption in health field made way for healthcare 3.0 where use of electronic health records (EHR) was used for maintaining the health records. Healthcare 4.0 is the adoption of Artificial Intelligence (AI), cloud computing and fog computing technologies. The healthcare 3.0 was based on hospitals and patient with complicated diseases had to go through hectic hospital visits for long period of time which added to their misery. The healthcare 4.0 is transforming the healthcare by providing diagnosis and treatment plans in the comfort of their homes. In addition to this, constant monitoring is made possible and any sudden health deterioration can be monitored and help prevent any fatality. A three-tiered architecture is developed which is patient centric rather than hospital centric which help in better healthcare provision [34].

The drawbacks related to the cloud are discussed in this paper. The benefit of incorporating the fog computing layer in the healthcare can improve the delay, network consumption and power consumption. A fog-assisted Internet of things (IoT) health monitoring is proposed based on these parameters. A three-layered approach is used in which sensor data goes to the smart gateway to process critical information at this point. Two types of sensors are used in the proposed solution. Medical sensors gather patient data like ECG, temperature and heartbeat. The application runs on a Raspberry Pi Zero board form Adafruit which is most suitable platform IoT deployments. The results show how the traffic on network is reduced. The security protocols can also be implemented and better understanding patient data is made possible [35].

An anonymous and privacy reserving data aggregation scheme (APPA) is used in this paper. It is a layered architecture which has IoT components: (1) Smart device (SD), (2) Fog node

(FN), (3) Public cloud Server (PCS), (4) Trusted Certification Authority, (5) Local Certification Authority (LCA). SD has capability to collect the data and send it to FN. FN processes it and send aggregated data to the cloud. This removes unwanted data from the traffic. TCA and LDA add security feature as well making the data protected. It results in minimum computation and minimum communication load on the network [36].

In this paper, a new mechanism is produced which is called Task classification and Virtual Machine categorization. This mechanism is based on the importance level of the tasks that arrive at fog node rather than priority being given to the tasks based on their length which is unfair distribution. Three categories of tasks are made which are critical tasks, important tasks and general tasks. The critical tasks cannot face any delay and need immediate processing. The important tasks require the processing in specified amount of time. The general tasks are tasks in which delay in processing would not result in failure of the proposed solution. Waiting time, finish time and execution time are measured using MAX-MIN algorithms. CloudSim simulator is used to measure these values and show the impact on dividing the tasks in categories on the overall working of the algorithm [37].

The large amount of data, produced on daily basis produces large amount of information. This demands new service to be developed that can deal with the large amount of data. This paper proposes a fog service named as Sieve, Process and Forward (SPF) which is an information model to deal with such large amount of data. SPF allows processing of data in fog as well as in cloud technology. The data is of three types in SPF service. Raw data form sensors which are collected on the runtime. Information objects are data which have gone through initial processing. Consumption Ready Information Objects are information which is returned to the user [11].

The quality of service (QoS) perspective is taken care of in this paper. A layered architecture that contains things, fog nodes and cloud is used for incorporating in a framework. There is high level coordination among the nodes n this architecture so that resources are utilized efficiently when achieving low response time. Task allocation is done in manner so that delay is minimal. This feature leads to its use in healthcare system for better provisioning of health services. The communication between the nodes is necessary for a well-coordinated efforts to serve the latency sensitive medical applications [38].

A fog system is proposed for emergency and disaster management. The system is called Emergency Help Alert and Mobile Cloud (E-HAMC) which has the capability of dealing with a variety of emergency situations. An E-HAMC application is used in time of distress by pressing a button on the application. The address is geometrically calculated and sent to the concerned authorities. The family members are also notified. The fog nodes process data quickly and also provides best route for providing the health services. This helps in dealing with emergency situations more efficiently [39].

One of the most lethal forms of disease that can be caused by mosquito bite is Dengue which in infect million around the world each year. Symptoms emerge in 6-10 days. A fog computing framework is proposed which is a three-layered architecture. The bottommost layer is the IoT layer. The middle layer is layer in which fog infrastructure is deployed and top layer belongs to cloud computing. The dengue patients are classified into uninfected, infected and severely infected based on their data. The classification process is carried out by studying the symptoms of patients. The process is expediated by use of devices in the fog layer [40].

IoT enabled healthcare services are made better by addition of fog layer. It is used in this paper for electrocardiogram (ECG) as it can study the condition of heart and study related heart diseases. The ECG has components of heart rate, P wave and T wave. These components are studied at the smart gateway at fog level. High level services are provided by the smart gateway. The results show a decrease in bandwidth utilization by 90% and much faster response time. This can save patients from cardiac arrests by taking emergency measures to prevent it [41].

There are patients that are not able to express their pain in the Intensive Care Unit (ICU) which results in their suffering for longer period of time until the reason is determined. A three-layered architecture is used to provide relief to the minors at the earliest. The first layer includes the sensors that can detect and send the EMGs and ECGs of the patients. The second is the central layer fog nodes are placed. They are connected to sensors Wi-Fi module. Image processing is also used apart from the ECG and EMG to determine the levels of pain the patient is going through. The third layer is of cloud. The cloud helps in processing of tasks at a later stage. It also provides storage capacity. There is a web application to view the pain parameter of the patients in run time. This lowers the workload on medical staff. The fog nodes help in reducing the latency and network consumption which are primary feature of medical applications [42].

A deep understanding of fog and mist computing is acquired with respect to its application in medical field. A major list of applications is evaluated, and a list of application specific tasks is made which can be catered by fog or mist computing. It is discussed that where the fog and mist computing can be placed in a network. It is determined that which layer should be fog and mist computing be squeezed for successful implementation of these computing paradigms. Three important aspects are discussed in this paper. First, there is large amount of data that are produced by sensors that are associated with Internet of Health Things (IoHT). These computing paradigms are best for such large amount of data. This large amount of data can be processed very efficiently. The short comes of the network can be overcome by having hierarchical structure of many tiers. The data can be preprocessed or aggregated at this level before sending it outwards. The third aspect that has been addressed is of security and privacy. As data can be filtered locally, sensitive data of patients can be safeguarded. Wrong treatment based on false information can be avoided. There has also been considerable amount of research on how to make most out of the algorithms. The findings show that adopting fog and mist computing for medical application can make Internet of Heath Things or Internet of Medical Things, more viable. Healthcare is highly essential and can be provided in best possible manner by using these computing domains. There are three components of the system. First is the sensor and actuators which are connected or present in close proximity of patient. It sends biomedical data. Second is Gateways which plays a bridging role. Data filtering and aggregation is done if proper data is provided. Third is the backend system which keeps large amount of data for carrying out analytics which can be helpful for future use. Local processing unit is used for handling data locally. This proves critical in emergency medical conditions. Data filtering is carried out to remove the unwanted disturbance in data. This disturbance corrupts the original data. Some transmission techniques can be used to remove these unwanted signals. As the data produced by the large number of sensors will be abundant so it can be compressed so that bandwidth is not wasted when data is sent to the cloud. The data that is lost as a result of unwanted noise in the bio signal data can result in wrong diagnosis which causes human loss. These problems can be dealt at the intermediate nodes where necessary techniques can be applied to recreate the original correct data. Some critical events which can raise the red flag and need immediate attention can be tackled at these nodes. Some action or mechanism which needs to be initiated after a crisis occurs is implemented here. Lower latency is achieved when launching theses mechanism and serves the purpose of medical applications [43]

A complete solution is provided by combination of cloud, fog and mist computing services for medical facilities provision which is based on Internet of Health Things (IoHT). The solution also caters for the security aspect of the problem as large amount of complex data is produced by the end devices in Internet of Health Things (IoHT). The energy that is consumed in transmission of data from end node to central cloud in normal method of transmission will be much more than the energy that is used when data is processed locally, which is the case of the research taken in this paper. Securing data in such large amount is also a challenge. A scheduling algorithm is introduced for a better utilization of energy. This algorithm is named as sleep scheduling algorithm. The framework also has the facility to deal data in batch mode and real-time. Fog computing provides decentralization and processing of data. It acts as a gateway where data is filtered before it can be transferred to cloud for further processing or storage. The mist computing brings some computational power to sensor part of the infrastructure because data transferring is more consuming than processing it locally. This help in pre-processing of data before sending it to the cloud. This also provides opportunity to control the sensitive information from traversing the network and reaching cloud. It provides security in this manner. Increasing the number of active nodes increases processing. This will give rise to more energy consumption and in the end energy of the nodes is drained. To counter this, some nodes which are not in use are made inactive so that they do not process or transfer data, so energy is not consumed as in previous case. This is sleep and wake algorithm that is used in this research. This is also termed as duty cycles. It is considered that abundant amount of health data is produced by patients. If this is to be transferred, a huge amount of energy will be wasted. Connected K-neighborhood which is known as CKN makes use of sleep intervals at regular pace. The no of active nodes is kept under check. If the connection can be maintained by few nodes, then other nodes are put to sleep if not needed for processing. By doing this k- awake neighborhood will have more energy increasing the lifespan. The results show how fog based IoT enabled medical service facility can consume energy efficiently [44].

## 3.3 Simulator

The technological uprise in the past 50 years has been unprecedented and as a result more advance digital computers have emerged. The information technology era has boomed in every field of life. The ‘think’ capacity of computer will cross the human brain power in the next 30 years. It is due to these facts that simulation and modeling of complex systems has been made possible. The high computing power has paved way for modeling and simulation of real-world environments [45].

The experimentation on real environment is not feasible in many situations because real world sources would be consumed. It would not be suitable to build and modify the real-world systems again and again as it can be costly as well as risky [46]. Due to high tech devices, it is possible that simulations are done in which mistakes can be corrected. Moving ahead or backward in timeline is achieved through simulation. In addition to this, repetition of experiments without consuming real world entities has made many real-world systems which could not have been possible. Doing experiments in real world before testing and validation is time consuming, irretrievable and costly as well. It is comprehensive way of understanding the problems and their best solutions in an experimental environment [47].

CloudSim is a simulation tool this is base for many clouds related technologies. It helps in modeling of virtual machines (VMs) on cloud datacenters and linking tasks to their respective virtual machines so that the tasks are executed successfully in required amount of time. CloudSim has classes to represent each and every resource that is related to cloud deployment. It helps in modeling and simulation of datacenter virtually in a cloud environment. There are separate interfaces for Virtual machines (VM), storage and memory for management purpose. It also helps execution of entities like data centers, hosts and virtual machines. Virtualization concept is used mainly in the simulator. Service broker has list of tasks that need to be executed as well as the virtual machines that are idle. It maps the cloudlet tasks to the virtual machine according to the policy that is deployed on it. The working is shown in diagram. The communication that takes place is shown in diagram [48].

Many companies like Cisco are working to provide data processing services of IoT data closer to the nodes which are producing the data. The components like Cisco IOx equipment, cloudlets and nano sever have served the purpose. This paper proposes a simulation framework called iFogSim for the simulation of edge computing technologies including fog computing. The underlying framework and base structure that is provided to the iFogSim is of CloudSim framework. The basic classes that the CloudSim offers for abstraction are also extended to the iFogSim simulator [49].

The architecture of IFogSim is layered in which sensors and actuators are at the bottommost layer while the fog devices are above this layer. The layers associated with the applications are at the top. It has monitoring components which make sure that the sensors and actuators are present for the simulation to take place. It also keeps the utilization parameters under check Resource Management helps in Quality of Service (QoS) maintenance of app and minimizing the wastage of resources. IFogSim supports Sense-Process-Actuate Model in which data is collected by the sensors and sent to the application that is deployed on iFogSim. The data is processed in these devices and necessary commands are sent to the actuator to perform required actions. Directed Acyclic Graph is used to model the application. The vertices show the processing sites of the data and edges represent the dependences between the modules [50]. The components that make up the application is based on three classes: (1) AppModule, (2) AppEdge, and [3] AppLoop. AppModule class defines the processing capability of the application. It has an outgoing tuple for each incoming tuple. The rate at which the output tuple is procedures is based on fractional selectivity. AppEdge defines the dependency of one module on the other. AppLoop can be altered to find the amount of time spent form one end to another in the network. CPU, RAM and bandwidth are three parameters which describe the processing power of a node. Two types of edges are allowed i-e periodic and event-driven [50]. The tasks that are beyond the compute capability of a node are sent to external processors. The external processor can be fund in cluster, grid or cloud. This offloading mechanism of laying off computation intensive tasks to other nodes because of computationally challenged nodes can make the tuple processing impossible. Path is used which is a set of nodes form leaf to not node. The computation need of modules is measured and then suitable node is selected that match the computation requirement so that the processing is made possible [51]. The storage and processing capabilities are managed at different levels by using data placement algorithms. Three schemes are used which are cloud only edge ward and mapping. The Edge ward algorithm is based on first come First serve (FCFS) policy. This policy pays importance to placement at the edge only. The algorithms make sure that data is placed on the closest edge of the network. The requests are catered based on the resources that are available at the earliest. If the computation ability does not meet the application demand, then a node on higher level of architecture is chosen for processing if it can meet the demand. The Cloud only placement is based on delay priority strategy. All application modules are placed directly on the cloud whatever their need of computation is. The mapping algorithms tries to place the module on the fog nodes preferably otherwise it will place the module on the cloud [52].

# Chapter 4

# 4. Implementation

## 4.1 Introduction

This chapter explains in detail the architecture of our framework. The framework is based on mist computing for the purpose of solving delay and latency for the medical application that is caused by cloud computing in the IoMT environment. It shows execution time and total network usage is also reduced. It includes how data flow from one component of the architecture to the other part of the architecture. The actors that are involved in architecture are also discussed. The layered perspective is also given for better understanding of the framework. The benefits of simulation are presented as well. The implementation has also been put forward in detail.

## 4.2 Basic Architecture

In our framework which is shown in figure 3, the patient would be wearing a IoMT device which include smart watches, smart glasses, medical wearable, activity tracker or even have some ingestible. Raw data will be collected from the sensors of the IoMT devices and sent towards the mist node. The mist node is present in order to cater the latency issues that are associated with the cloud. The growth of IoT in medical field fails because of this drawback as quick response is needed in order to save important lives. The mist nodes take care of this issue by processing the received raw data quickly. The delay sensitive applications are provided with quick response by not sending all the data to the cloud but processing it locally. It relieves the network of burden of sending data to the cloud which consumes bandwidth Mist node implements mist computing which is an extension of cloud computing rather than the substitute. It brings some of the processing capabilities of cloud computing towards the edge of the network in order to have a better response time. Based on the processed data, the actions that need to be taken urgently are sent to the actuator. The tasks that can be postponed can be sent the cloud. The data that can be kept for record purpose so that history of the patient remains in the system is sent to the cloud. The data that is coming from the IoMT devices is also sent regularly to the cloud so that the doctor who is at distance from the hospital can be updated about condition of the patient. The data from the mist node goes in two directions after processing of raw vitals of the patient. The tasks that need prompt action would be sent to the actuator so that necessary response is made as soon as possible. The medical staff that is onsite would receive the necessary commands that need to be performed for the immediate relief of patents. The commands are delivered to the patients in a very short span of time. The processed data that can be deferred or do not need immediate attention are sent to the cloud. This data may be for record keeping purpose or that require doctor's attention. The data of patient is sent to the cloud so that the doctor is well informed about his patient's condition. Exchange of data and command occurs at this level between cloud and the doctor. The doctor analyzes the data and send set of instructions to actuator. The medical staff make use of these instructions perform the task of action delivery. The commands that come from the doctor can override the commands that have been sent from the mist node. The reason is that the mist nodes take care of immediate actions that are needed to save life. The commands that come from doctor via cloud are after detail analysis

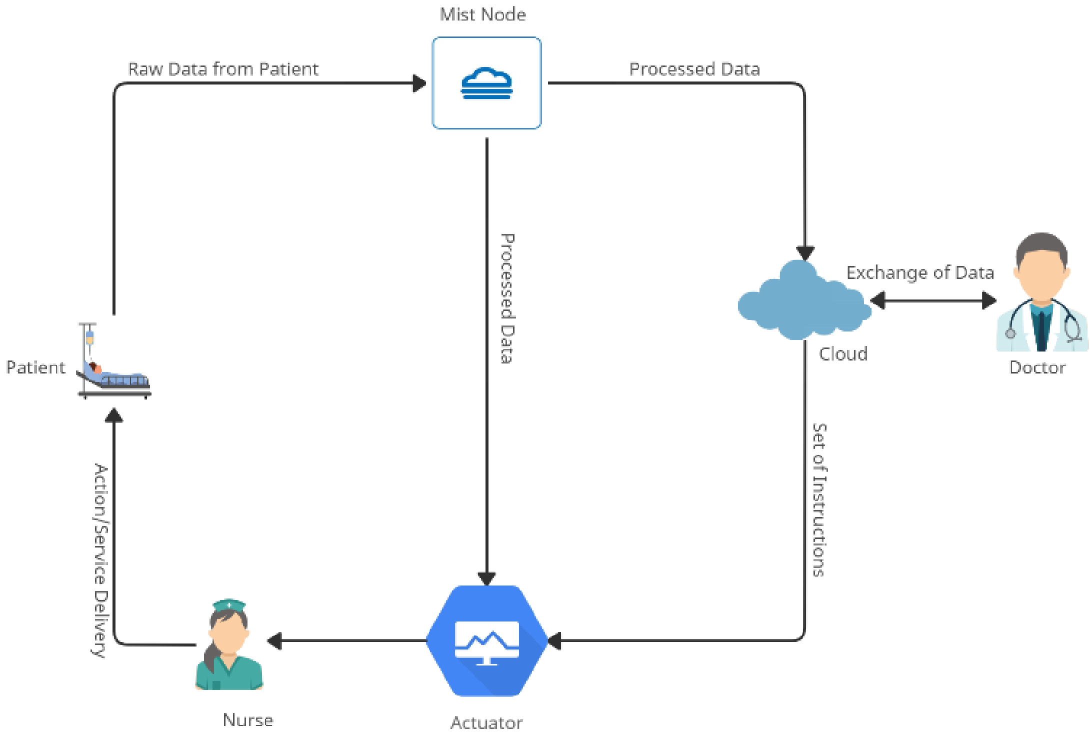


**Figure 4: Basic Architecture for Proposed Framework**

of the processed data about the patient. The medical staff cares about this matter and is responsible for medical service delivery.

## 4.3 Actors

In the architecture, there are three main actors who play an important role. First is the patient who is in distress because of an ailment. The patient is wearing IoMT device which has critical role in observing the bio signals of the patient. The IoMT devices can have multiple health applications which include monitoring patients remotely, treatment as well as rehab purposes. The sensors in IoMT devices will have ability to monitor pulse, respiration, temperature, blood pressure and oxygen level in the blood. The doctor who has enough knowledge to diagnose the disease takes necessary actions to cure it. He is located at remote location from the hospital. He studies the data that is received for the smart devices and analyze the data. After analyzing the data, calculated action is sent so that medical relief effort can take place. The third player who plays primary role is medical staff who has enough training to carry out the instructions that are required for the treatment of patient. They deliver relief to the patients. The medical staff is medium through which the diagnostic and cure procedures that are proposed by the doctor who is at remote location, can be initiated. The patient is relieved of distress after necessary action takes place.

## 4.4 Implementation of Application Model

Implementation on real time environment is difficult as many aspects are to be taken care of. Experiment cannot be performed repetitively in real environment. In addition to this, specifications cannot be altered once a physical system is built. Scaling is not easy to achieve in real environment. There is high risk of failure of system if it is directly deployed on real world environment. Simulation provides us with this opportunity to test everything before deploying it in real world. It helps in avoiding any hassle that can be caused by direct real time implementation. According to researchers, the most suitable simulator for fog and edge computing is iFogSim simulator. It is based on CloudSim which is another simulator for cloud computing. IFogSim is java-based simulator which is used by many researchers in the industry. IFogSim uses sense-process-actuate model to carry out its operations. IFogSim has classes which represent different components of the architecture. It has classes for fog device, actuators, sensors, tuples, links and end devices. Fog broker is used for scheduling purpose. The controller is used for placement of modules IFogSim has three components i-e App Module, App Edge and App Loops. App module is the processing where all the processing takes place. AppEdge is the link through which data flows form one application module to another. App loop is used to measure the latency that is cased when data moves from one point of the network to another.

There are three modules that are present in our framework. The names of important modules of our framework are Vitals Observer, Vitals Calculator and Master Controller. The whole logical representation of the framework is presented through these modules as shown in figure 4. The app edges through which data flow from one module to other module are _sensor, vitals state local, vitals state global, local state update and global state update. There is also a sensor and actuator as integral part of framework. The sensor node is through which data is sent in the framework and actuator is a node to which action is forwarded based on the processing in the application modules. Sensors collect the data from the patient who is in distress because of an ailment at the hospital. This module is at the extreme edge of the network which is very close to the sensor. The sensor sends data to the entry point of framework which is at close proximity of the sensor from where data has been collected. Vitals Observer is the entrance module of the framework. This module checks the validity of the bio data that has been received from the sensor. It checks if the data that is coming is corrupted or in some erroneous format. After validating of the data and pre processing at this module, the vitals of the patient that are collected are sent to the Vitals Calculator module. The data from the sensor to VitalsObserver goes through the _SENSOR edge. Processing is carried out data in this module based on the information collected from the previous module. Critical life-saving actions are based on the processed results of this module. From this module, data follows two paths. The first path is chosen in case of urgent response needed in which processed data goes to the actuator which has set of instruction that need to be carry out to save critical life of patient. The edge that is used local state update. The medical staff provides the service delivery. In other case, the processed data which can be deferred is send towards the master control module. The remote doctor whose consultation is needed can view this data in cloud environment. The doctor studies data and long-term treatment plan is made which needs to be followed after initial lifesaving activity has been performed. The doctor receives data after some time because cloud technology has delay issues. The doctor sent set of instructions which are taken as long-term plan of treatment. The edge that is used is global state update. The module at the edge receives data from two modules which are Vitals Calculator and Master Control. The service delivery is made possible through the medical staff which receives set of commands at the actuator. Vitals calculator module is placed in the mist layer as well as cloud layer depending on the scenario. The master control module is always placed in the cloud layer.

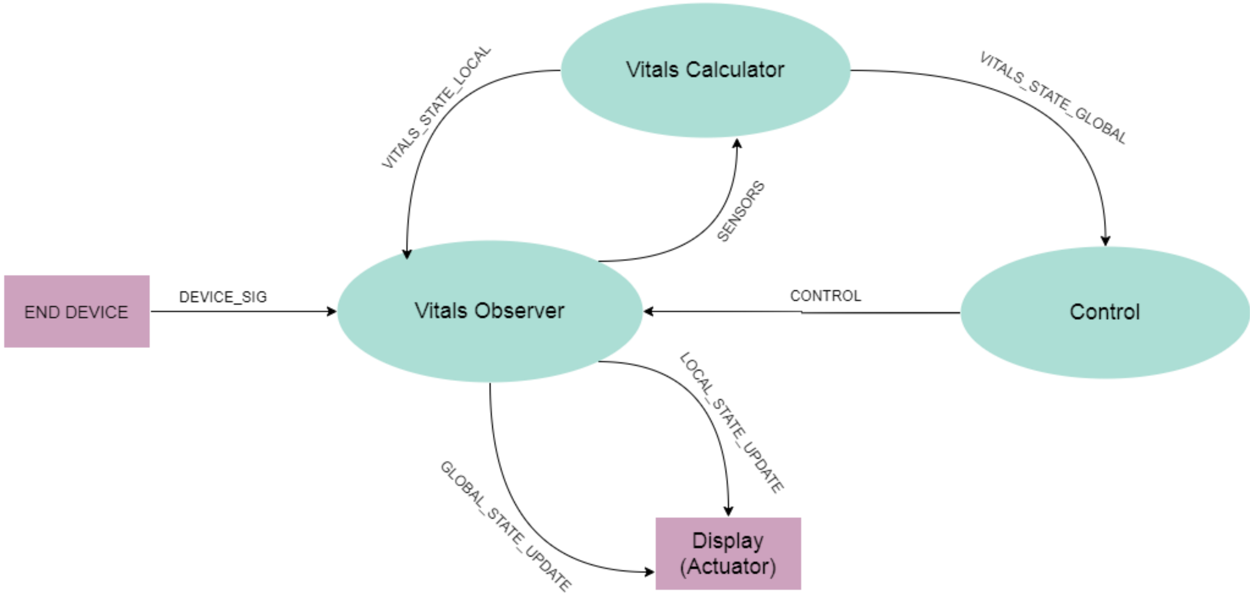


**Figure 5: Modules and working of Framework**

## 4.5 Physical Topology

Physical entities are created to build topology of the network. There are sensors which gather data and send it to the application. There are mist nodes and cloud datacenter that is established. Links are used to build a connection between the entities. The sensors are attached to the patients to provide physiological data. Processing elements are placed on the mist nodes while the master control is to be placed datacenter of cloud. The details of devices used in the topology are presented in table 1.

| Parameter | Cloud | Proxy | Mist | Sensor |
|---|---|---|---|---|
| **Level** | 0 | 1 | 2 | 3 |
| **Rate per MIPS** | 0.01 | 0.0 | 0.0 | 0.0 |
| **RAM(MB)** | 40,000 | 4000 | 4000 | 1000 |
| **Idle Power** | 16 x 83.25 | 83.43 | 83.43 | 82.44 |
| **Download BW** | 10,000 | 10,000 | 10,000 | - |
| **CPU Length (MIPS)** | 44,800 | 2800 | 2800 | 500 |
| **Uplink BW** | 100 | 10,000 | 10,000 | 10,000 |
| **Busy Power (Watt)** | 16 X 103 | 107.339 | 107.339 | 87.53 |

**Table 4.1: Details of Devices**

There are two sets of configurations which are used in simulation. Different scenarios are studied. The number of devices is increased so that its effect can be evaluated. The first set of configurations is shown in figure 6, 7, 8 and 9. The number of mist nodes is fixed to 4 and the number of end devices attached to the mist nodes increase as 1(Figure 6), 2 (Figure 7), 3 (Figure 8), 4 (Figure 9) and respectively. This configuration studies the increasing number of end devices.

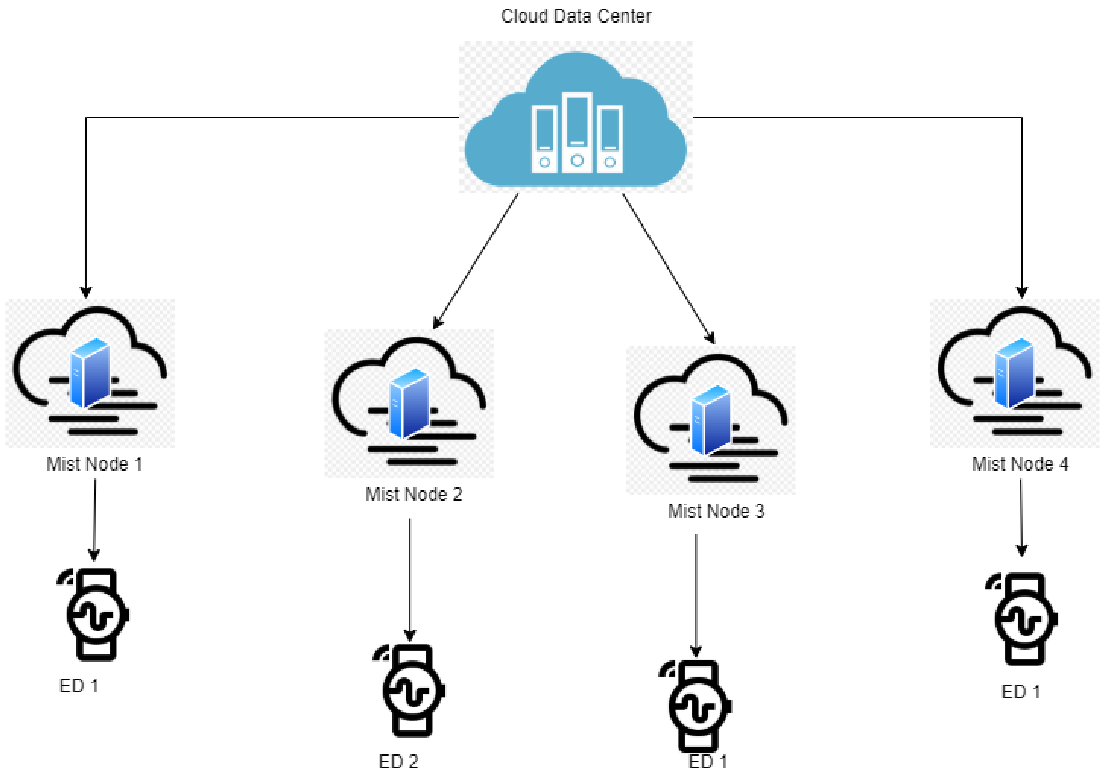


Figure 6: 4 Mist nodes and 1 End Device

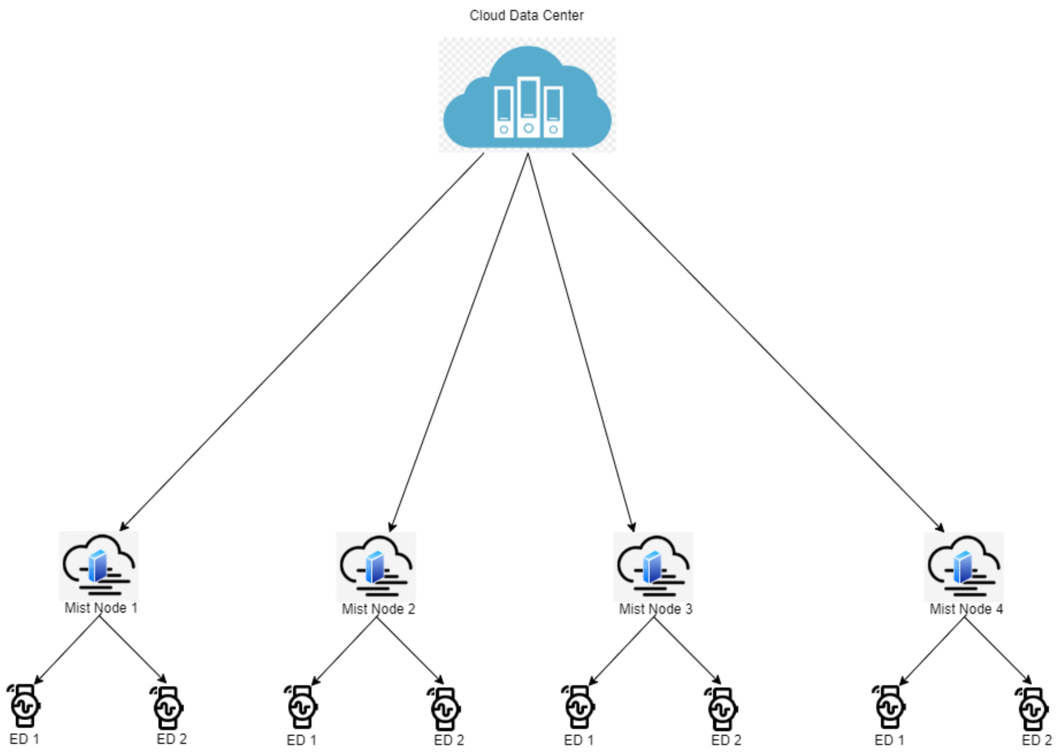


**Figure 7: 4 Mist Nodes and 2 End Devices**

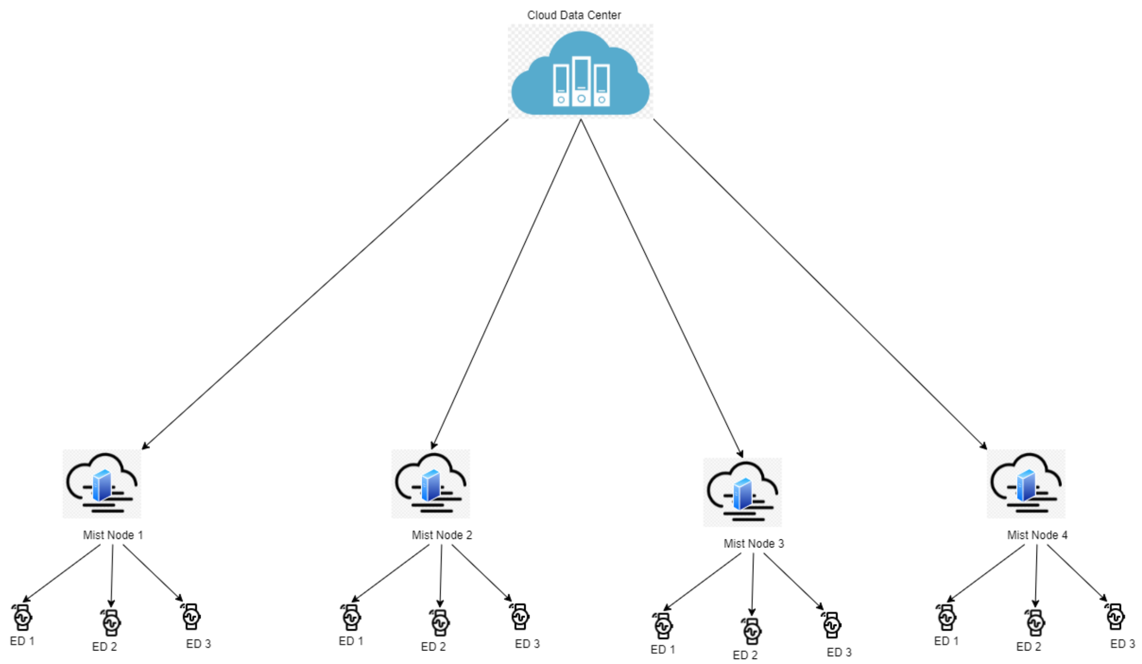


**Figure 8: 4 Mist Nodes and 4 End Devices**

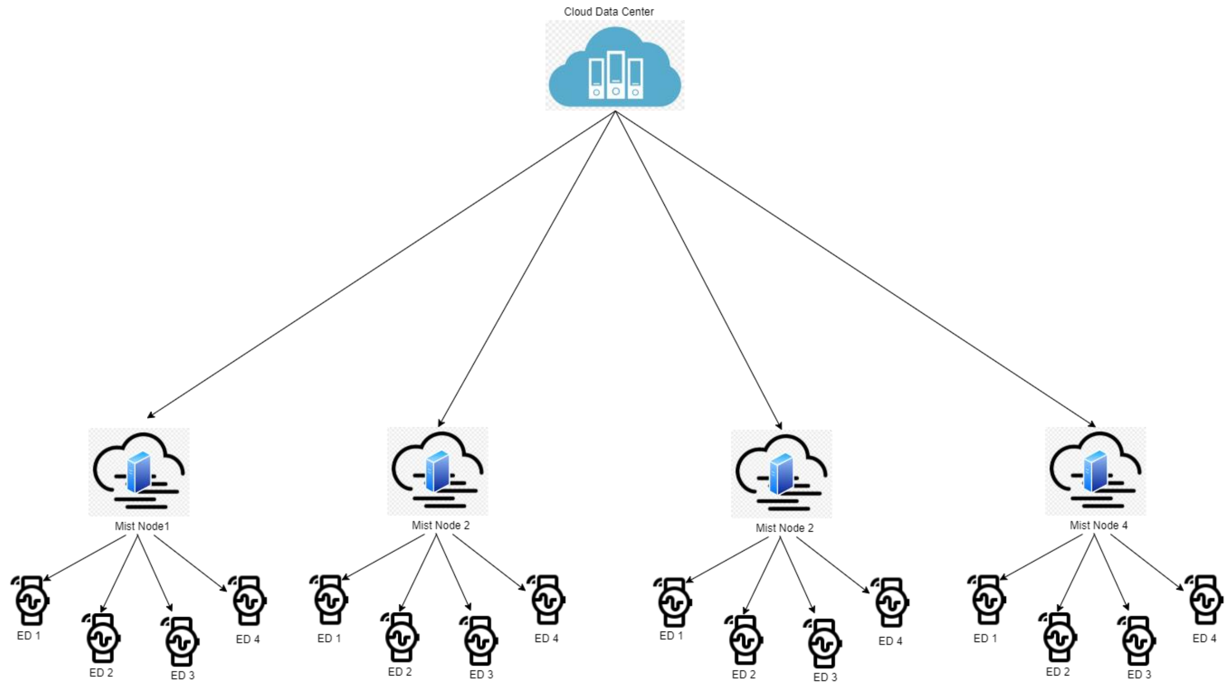


**Figure 9: 4 Mist Nodes and 4 End Devices**

The second set of configuration adds mist nodes to its topology in each simulation. This is used to study the effect of increasing number of mist nodes. The mist nodes increase as 1, 2, 4, 6 and 8 respectively. The topology can be seen in figure 10.

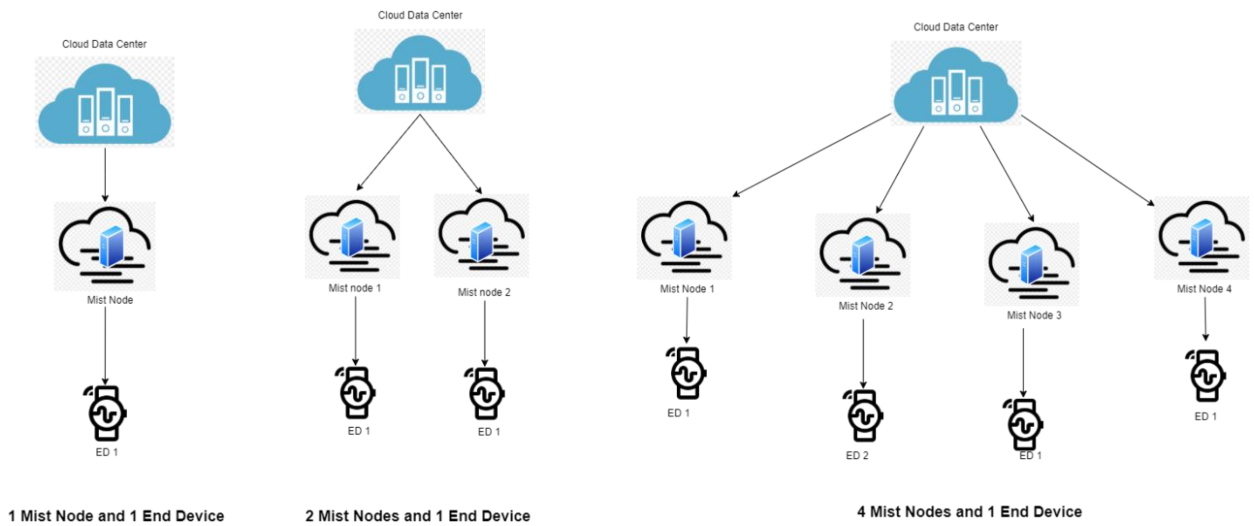


**Figure 10: Topology for constant End Device and Increasing Mist Nodes**

# Chapter 5

# 5. Analysis and Results

## 5.1 Introduction

The results that have been gathered when simulations are run on iFogSim are discussed in this chapter. There have been different set of configurations for this purpose. The simulation is run when considering only the cloud infrastructure as well as when there is a mist layer between the cloud and IoMT devices. The results have different parameters which were considered when compiling the results. There are two scheduling and placement algorithms used to cater the cloud and mist node deployment. The cloud only placement places the modules on cloud only while in edge ward placement, some modules are placed on mist layer while some are placed on cloud layer. There are two sets of configurations used in the simulation. In the first set, the number of end devices increases while the number of mist nodes is constant. This is done so that the effect of increasing end devices can be seen in results. In the second set of configurations, the number of mist nodes increase so that the increasing number of nodes can be monitored in results.

## 5.2 Average Delay

Average delay is an important parameter in the system. The medical applications require low latency to deal with emergency situations. Small delay can be the difference between life and death. The average delay is minimized when processing occurs at the mist node. It is calculated using the control loop of the application. Unit of average delay is mill seconds. Average delay increases as the topology gets bigger but drops dramatically when modules are placed edge-wards. The latency is lowered because the geographical proximity is minimum in mist deployment. If the topology size and emission rate of tuples increases, the reduction in edge ward placement is even more evident.

In the first set of configurations, the delay increases as the number of end devices increase while mist nodes are constant. The delay decreases when the mode of deployment is mist. The table 5.1 shows comparison delay between mist and cloud deployment based on control loop. The comparison can be seen in figure 11.

| Config | Average Delay-CloudOnly | Average Delay-Edgewards |
|---|---|---|
| Config 1 | 225.1496506 | 17.84065381 |
| Config 2 | 226.067126 | 19.20109619 |
| Config 3 | 226.0854913 | 26.34435573 |
| Config 4 | 226.4646988 | 53.77241032 |
| Config 5 | 252.7627059 | 72.13470591 |
| Config 6 | 1733.329963 | 112.4324511 |
| Config 7 | 3209.034244 | 152.7627059 |

**Table 5.1: Comparison Delay between MIST and Cloud Deployment**

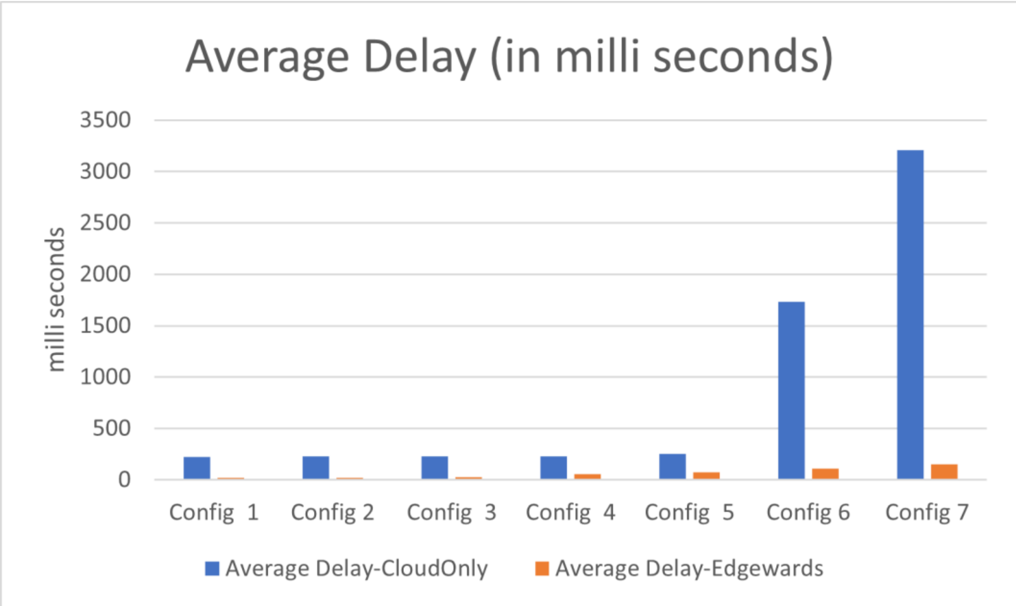


**Figure 11: Graph of Comparison delay between cloud and MIST**

In the second set of configurations, the mist nodes increase in order of 1,2,4,6 and 8. The results are drastic in case of cloud as delay increases but in case of mist it is much lower. The delay in case of mist is same because mist nodes are increasing while the end node is same. The delay that would be from end node to the mist node would be same in all mist nodes. The results are shown in table 5.2 and can be viewed graphically in figure 12 as well.

| Config | Average Delay-CloudOnly | Average Delay-Edgewards |
|---|---|---|
| Config 1 | 226.6077158 | 19.20109619 |
| Config 2 | 225.5762765 | 19.20109619 |
| Config 3 | 226.067126 | 19.20109619 |
| Config 4 | 1319.222185 | 19.20109619 |
| Config 5 | 3421.987686 | 19.20109619 |

Table 5.2: Delay in MIST Node

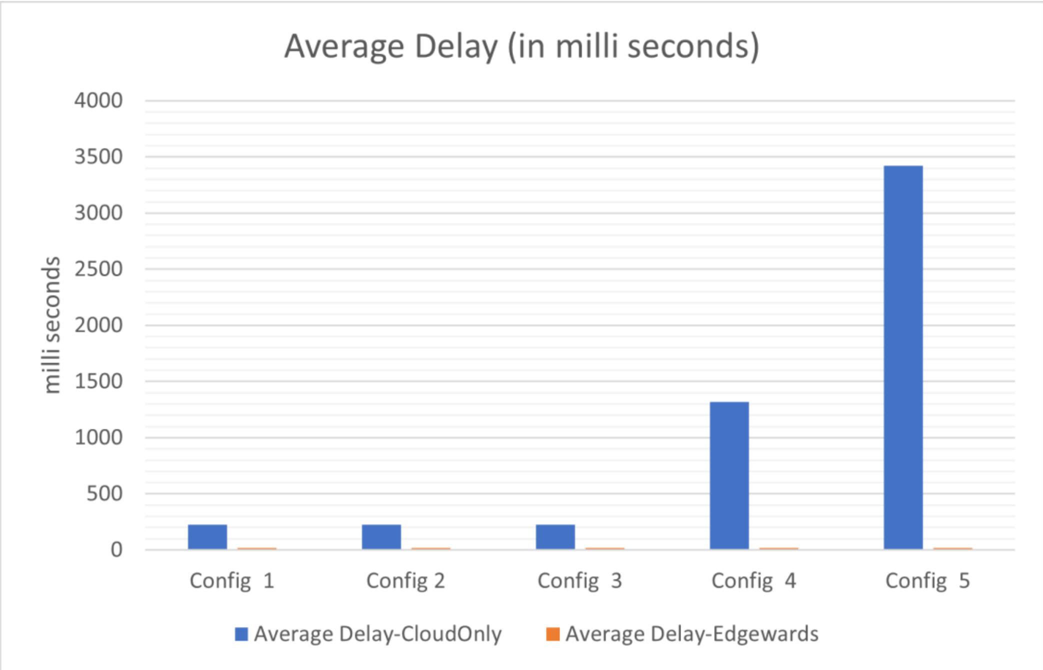


Figure 12: Graph for Delay in MIST Node

## 5.3 Total Network Usage:

The congestion in network increases when only cloud is used and traffic is increased. It also causes reduction in speed. It is the total amount of use of network resources. It is measured in Kilo bytes. It shows problem of scalability when network grows. Increase in number of devices significantly increases load on network. The mist layer between the cloud layer and edge devices significantly reduces the bandwidth that is consumed. When cloud-only deployment is used, all tasks that need processing or storage are sent to the cloud. The tasks have to start from one end of the network to another end of network covering the whole network. The public internet is also used which results in increase in utilization of important network components.

The table (5.3) shows increase in usage of network resource jumps high when number of end devices increase in cloud placement scheduling while on the other hand when mist node is used in between both layers the network is relieved and usage drops down. Increase in end devices does not result in sharp increase in total network usage. The figures 13 and 14 show the comparison between both modes of deployment.

| Config | Total Network Usage-CloudOnly | Total Network Usage-Edgewards |
|---|---|---|
| Config 1 | 92449.2 | 6941.2 |
| Config 2 | 189994.9 | 14331.6 |
| Config 3 | 293803.5 | 23316.8 |
| Config 4 | 403858.3 | 33609 |

Table 5.3: Network Usage in Cloud VS MIST for Set A

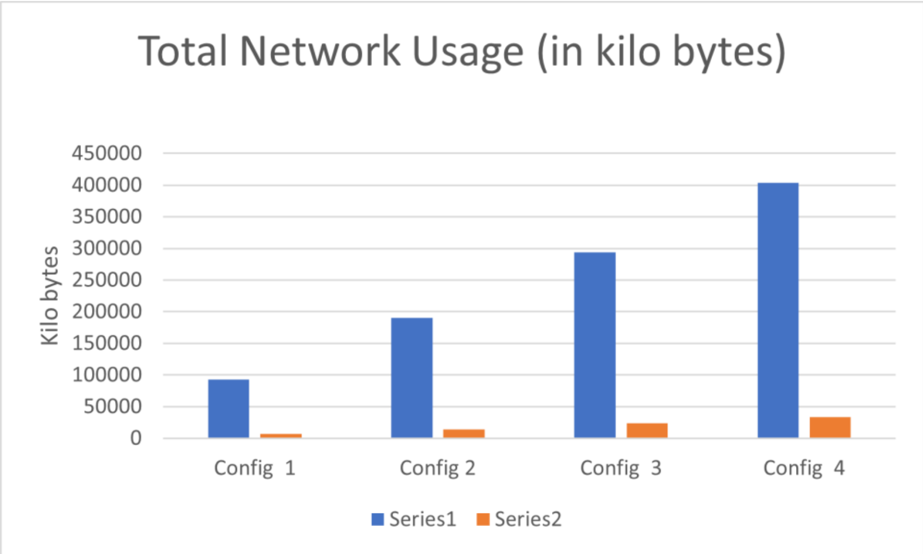


Figure 13: Graph for Network Usage Comparison between Cloud and MIST for Set A

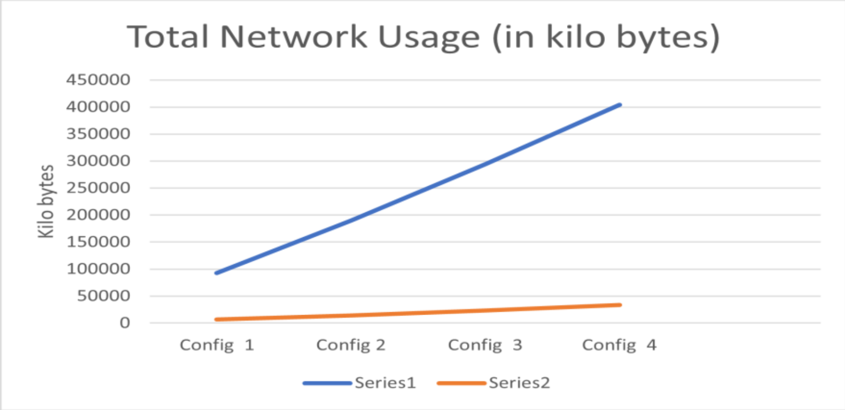


**Figure 14: Graph for Network Usage Comparison between Cloud and MIST for Set A**

The second set of configurations has increasing number of mist nodes. They increase in order of 1, 2, 4, 6, 8 and so on. The utilization of network resources is more in cloud deployment as the number of end nodes goes high. The mist nodes deployed reduces the network usage as some components of the network are not utilized when mist node is used. The values are shown in table 5.4 and comparison can be made through graphs as shown in figure 15 and 16.

| Config | Total Network Usage-CloudOnly | Total Network Usage-Edgewards |
|---|---|---|
| Config 1 | 43545.6 | 4325.4 |
| Config 2 | 89235.5 | 7660.8 |
| Config 3 | 189994.9 | 14331.6 |
| Config 4 | 406531.2 | 27673.2 |
| Config 5 | 570186.9 | 41014.8 |

**Table 5.4: Network Usage Comparison for Set B**

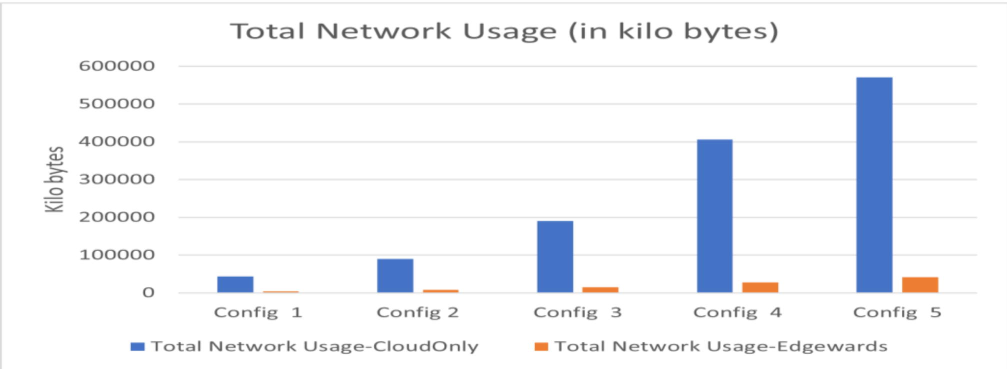


**Figure 15: Graph showing Comparison of Network Usage for Set B**

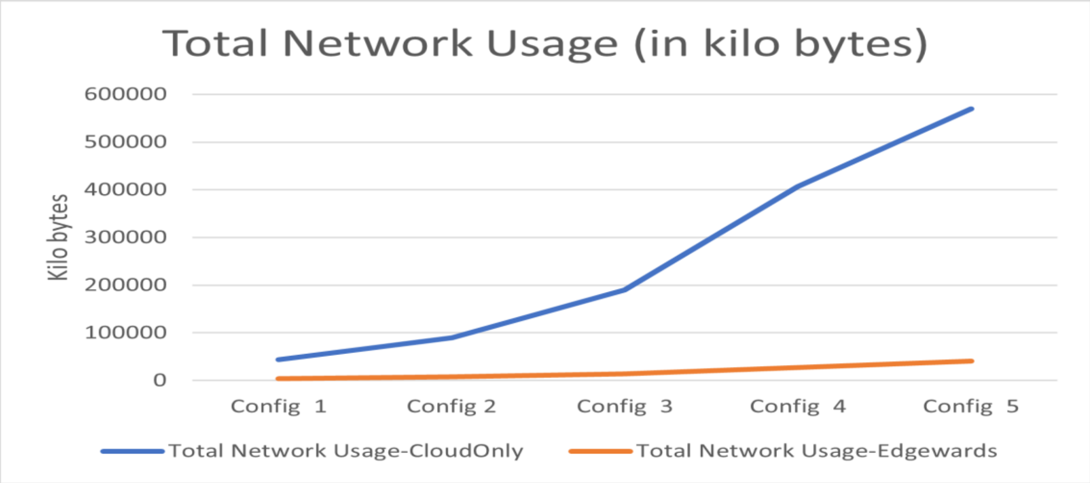


**Figure 16: Graph showing Comparison of Network Usage for Set B**

## 5.4 Execution Time

It is the overall time spent from placement of modules on nodes till the last tuple execution. It represents the overall time that that is spent. It is measure in milliseconds. The execution time is also less in the mist mode of deployment as in previous cases.

The table 5.6 shows the execution time as the end nodes increase as 1, 2, 3, 4 and 5 respectively. The comparison between the cloud computing and nodes can be seen in the figure 17 and 18. The increase in execution time of cloud is more than the mist computing when the number of end devices increase.

| Config | Execution Time-CloudOnly | Execution Time-Edgewards |
|---|---|---|
| Config 1 | 11585 | 9380 |
| Config 2 | 20538 | 11842 |
| Config 3 | 33572 | 16111 |
| Config 4 | 50909 | 31281 |
| Config 5 | 70125 | 67074 |

**Table 5.6: Execution Time comparison for Set A**

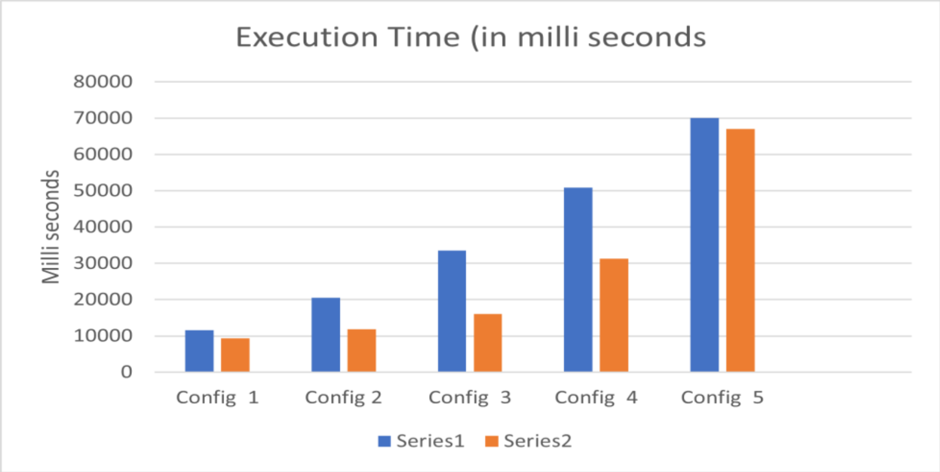


**Figure 17: Graphical Representation for Execution Time Comparison for Set A**

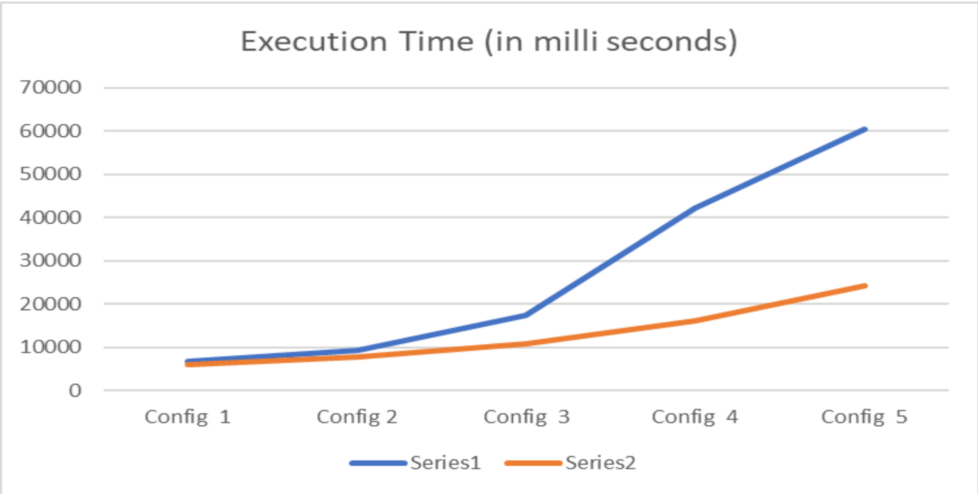


**Figure 18: Comparison of Execution Time between Series 1 and Series 2**

In the second set of configurations, the mist nodes increase. The values can be shown in table 5.7. The cloud-based values are higher than the mist-based values. There is hike in execution time when no of mist nodes increases. The increase in values is subtle in edge deployment.

| Config | Execution Time-CloudOnly | Execution Time-Edgewards |
|---|---|---|
| Config 1 | 6753 | 5994 |
| Config 2 | 9360 | 7744 |
| Config 3 | 17358 | 10785 |
| Config 4 | 42173 | 16087 |
| Config 5 | 60354 | 24322 |

**Table 5.7: Execution Time Comparison for Set B**

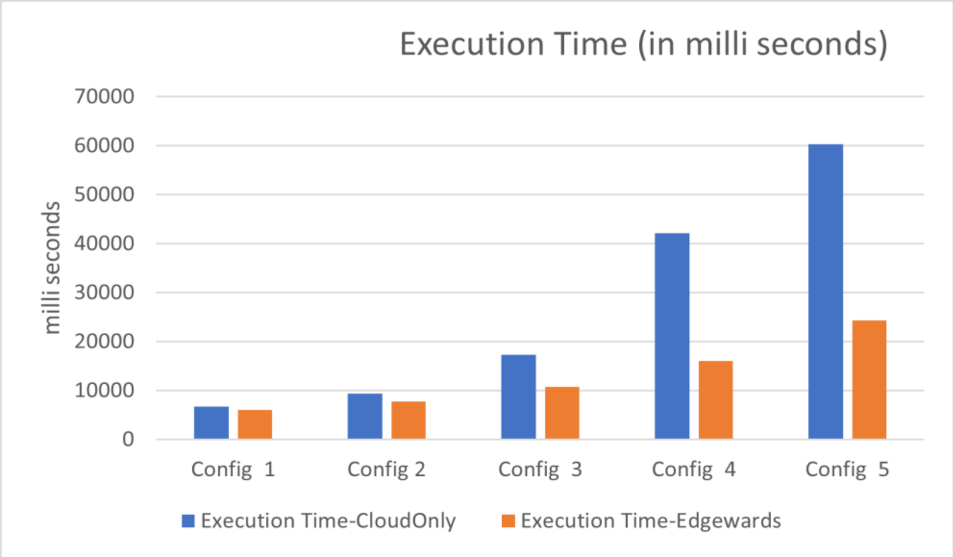


**Figure 19: Graphical Representation of Execution Time Comparison for Set B**

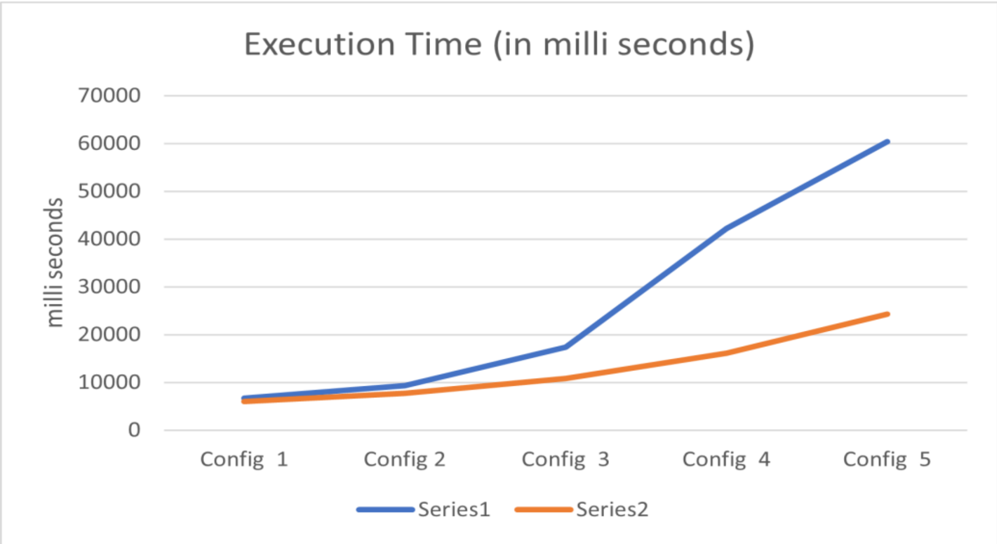


**Figure 20: Comparison of Execution Time between Series 1 and Series 2**

# Chapter 6

# 6. Conclusion and Future Work

## 6.1 Conclusion

The IoT based applications are not feasible if their latency is not minimal in accordance with the need of saving a human life. Any delay in processing may result I loss of life. The problem is resolved by deploying mist nodes resulting in better performance. The Mist computing framework specifically designed for delay sensitive medical applications has been proposed in our thesis. Framework uses MIST nodes between application and cloud layer to increasing processing, thereby increasing response time. The benefit of using this framework over traditional cloud architecture is proven by using iFogsim simulator. Two sets of combinations are used to prove improved results of using this framework in figures 13, 14, 15 and 16. Two factors are mainly focused while generating results which are Network Usage and Execution Time. It can be seen in the figure 14, that using MIST node has straighten the graph for network usage as number of both, Mist Nodes and End Devices increase while graph shows continuous rise in cloud-only architecture. The same is done for increasing Mist Nodes only, keeping the End Devices same and results show similar benefit which is decreased network usage. In this way, MIST Framework reduces the burden on Network while implementing IoT in healthcare applications. Another factor is Execution Time and as shown in figures 17, 18, 19 and 20, time taken for execution in both sets of configurations has decreased. The execution time which is the overall time spent by the task from inception till delivery is also reduced. The network usage which is the use of network resources is also reduced by mist nodes as processing is done locally without need of sending it to the cloud due to which network resources are used. Offloading is done by processing the tasks that can be processed locally at much faster pace and if local resources are not able to process the tasks, only then the tasks are sent to the cloud. By decreasing execution time and network usage, latency is decreased. Hence, MIST framework can be used in IoMT to get maximum benefits.

## 6.2 Future Work

IoT is currently young technology and has far to go to get where it is destined for. Healthcare applications are life critical and application of IoT requires accuracy and fast results as delay and wrong results may affect patient's health and might cause death. However proposed framework deals with the delayed results but the chances of wrong results still exist there. Wrong results can happen when alteration is made during processing. This issue is related with security of data that needs to be guaranteed during processing in order to fully use the potential of IoT in medical applications. The IoMT infrastructure along with MIST framework resolves latency problem but there is a dire need of strict security methods that guarantee security of data during processing. Further research is needed in terms of security so as to improve the efficiency of IoT in medical applications as alteration of data, affects life critical decisions. Moreover, this framework can also be further modified for other type of delay sensitive applications.

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