Fog Computing-based Internet of Things and its Applications in Healthcare

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Abstract. Internet of Things is the most revolutionary and attractive technology of today, which employs a combination of sensors, embedded systems, software and artificial intelligence. These devices are usually coupled with the cloud to produce significant insights. However, the cloud comes with its own issues such as network latency and jitter, which makes it inappropriate for delay-sensitive applications such as healthcare. Hence, a novel paradigm came about known as fog computing, in which computation is carried out at a data collection edge/source. In this paper, we have studied fog computing in a bottom-up fashion, starting from its key features, merits, and then an architecture to show that its integration into a traditional cloud-based IoT system makes it suitable for latency-sensitive applications. We have further made a deep dive into how fog-based IoT systems can be utilized in the field of healthcare, studying the architectures for context-sensitive and at-home healthcare monitoring.

Keywords: Internet of Things, Cloud Computing, Fog Computing, Latency-Sensitive, Wireless Ad Hoc Networks, Healthcare Monitoring.

1 Introduction

Internet of Things (IoT) represents the interconnection of numerous physical objects (“things”) each having a unique identity (IP address). IoT is the most revolutionary and attractive technology of today, which employs a combination of sensors, embedded systems, software and artificial intelligence to produce significant insights. It has a broad range of applications such as wearable devices, smart cities, home automation, etc. The IoT devices are typically constrained with respect to size, and possess limited processing power and storage capability hence they come with many issues such as reliability, scalability and privacy. A practical solution to solve these problems is with the coupling of cloud computing with IoT to form an architecture known as the Cloud-of-Things (CoT). The CoT enables centralized data storage, fast processing ability to apply machine learning algorithms, rapid deployment with minimal cost and scalability in terms of allocation of resources. This highly improves the quality of service (QoS) to the end-user.
The CoT architecture can be thought of as 2 layers. The bottom layer contains millions of sensors connected to each other. These devices collect numerous types of data via different sensors such as pollution sensor, thermal sensor, electrocardiogram (ECG) sensors, hyperspectral sensor among others. These may also include mobile phones, smart glasses, smart vehicles and has the function of collection of data. Whereas, in the top layer, the cloud implements IoT applications and services for the user using the data retrieved using the bottom layer. The two layers are connected using network devices such as routers, switches, and use standard communication protocols to exchange data.

Despite the benefits of CoT, it is not a one-stop solution for all the problems in IoT. This is due to the fact that there is a high latency associated with CoT in addition to network jitter, which is caused by a concentration of data storage at one central location. Moreover, since the amount of data collected via IoT devices is voluminous and needs to be transferred to the cloud, the CoT architecture is not appropriate for delay-sensitive IoT applications such as healthcare services and Internet-connected vehicles, wherein accidents could take place due to the latency caused by the cloud-based approach.

Hence, the need arises for the introduction of a novel paradigm in the current CoT architecture to support delay-sensitive IoT applications. Fog computing was defined [1] in 2012 as “an extension of the cloud computing paradigm that provides computation, storage, and networking services between end devices and traditional cloud servers.”

The rest of the paper is organised as follows: Section 2 describes the features of fog computing in detail along with its merits, how it compares with cloud computing and a six-layer architecture for fog computing. Section 3 introduces the importance of utilizing fog-based IoT in the field of healthcare technology and also explains an architecture for context-sensitive healthcare monitoring. Section 4 studies an architecture for “at-home” healthcare monitoring using fog computing and further describes a pseudocode for data analysis in the fog node.

2 Fog Computing

2.1 Features of Fog Computing

Fog Computing must not be thought of as a replacement of the cloud, but complements it Figure. 1. It is essentially an extension of the cloud, in which computation is performed at a data collection edge/source. As depicted in Figure. 1, the present CoT architecture is converted into a Fog-of-Things (FoT) architecture via the integration of a fog layer among the cloud and the multiple kinds of sensors. The fog layer contains various fog nodes. A fog node needs to have the essential requirements of having a network connection along with processing ability and storage. Hence, the devices which act as fog nodes are routers and switches. Local data analysis and storage is carried out at fog nodes, and global analysis and storage is performed at the cloud. The main purpose is the reduction of the data being transferred to the cloud thereby improving the performance and efficiency. The authors have given a brief description of how fog computing compares to cloud computing in Table 1.
Figure. 1: Conversion of CoT to FoT by introduction of Fog Layer

Table 1. Differences between Cloud and Fog Computing

| Features                | Cloud Computing          | Fog Computing            |
|-------------------------|--------------------------|--------------------------|
| Latency                 | High                     | Low                      |
| Deployment              | Centralized              | Distributed              |
| Client and server       | Multiple hops            |                          |
| Single hop separation   |                          |                          |
| Server Nodes            | Within the Internet      | At edge of the network   |
| Location-awareness      | No                       | Yes                      |

2.2 Merits of Fog Computing

- Low Latency: Since there is only a single hop distance between fog nodes and the sensors
in comparison to multiple hops in case of the cloud, the latency of the response is very low.

- **Scalability**: Less distance of fog nodes to the sensors allows increasing the number of connected devices.
- **Location Awareness**: We can trace the location of fog nodes to support devices with rich services. The devices’ regions can be found out based on location of fog nodes.
- **Decentralization**: Self-organization of fog nodes is possible to provide IoT applications to users.
- **Lower Operating Expense**: Processing of selected data locally and sends the data selected by fog to cloud for historical and future use, thus saving on network bandwidth.

### 2.3 Six-Layer Fog Computing Architecture

The six-layer for computing architecture is shown in Figure. 2. The first layer is the physical layer which has various IoT devices of two types: mobile and fixed. Some examples of mobile ones are connected vehicles, smart phones and smart watches. The communication between all devices that belong to a particular person may take place through wireless ad hoc networks that use wireless multi-hop relaying to communicate information from a source node to a destination node. These networks are capable of operating without any fixed infrastructure.

On the contrary, the fixed IoT devices include various kinds of sensors which are geographically distributed to fulfill tasks such as air quality monitoring, forest fire detection, etc. In the monitoring layer, the availability of sensors and fog nodes is monitored along with the energy consumption. The pre-processing layer has the task of analyzing collected data along with filtering of data to extract meaningful information. Data storage takes place with the use of the temporary storage layer. Encryption/decryption is the main function of the security layer. The last layer is the transport layer where the data is sent to the cloud to
produce insights and deliver beneficial services to the end users.

3 Fog Computing in Healthcare

3.1 Motivation

Wireless Sensor Networks (WSNs) are of very high utility in the field of healthcare technology. Wireless sensors are revolutionizing this area, being attached to patients are wireless wearable devices or accessories. These help in monitoring patients who are at risk due to chronic diseases, both for safeguarding them in the situation of a sudden attack and ensuring compliance to treatment plans. A classic CoT architecture would not be feasible in the field of healthcare technology because having patient data being stored outside is not something any hospital would prefer. Moreover, there might be the failure of the data center itself, which can cause data loss which directly affects all patients. There can also be delay caused in transferring the data to cloud from sensors or from cloud to hospitals. It is no secret that time is of utmost importance in the case of any medical emergency, i.e., healthcare monitoring of patients is a latency-sensitive application. Hence, we need to convert the centralized cloud architecture to a distributed one. This is where fog computing comes into picture.

![Figure 3: Context-Sensitive Health Monitoring Architecture](image)

3.2 Context-Sensitive Health Monitoring

There is a need for efficient processing of information collected from WSNs to provide personalized health care to all patients. Context herein can be of 2 types: extrinsic context and intrinsic context. Where intrinsic context can be found out by employing biosensors, extrinsic context is related to factors such as the environment surrounding a patient. The combination of both is used to gather information for patient monitoring. However, the type of relevant data differs depending on the disease suffered. The architecture for such a system is shown in Figure. 3.

**Sensors Layer:** It consists of the sensors which sense extrinsic and intrinsic information. Examples of extrinsic are location and temperature whereas that of intrinsic are heartbeat, blood pressure, etc. The data collected via sensors is sent to the fog layer.
Fog Computing Layer: Primary role of distributing processing tasks to the devices connected to it by employing a task-scheduling algorithm. Moreover, it has the function of data analysis and data aggregation.

Cloud Computing Layer: It has the primary role of management and supervision of the actions that are carried out by the fog computing layer.

3.3 Work Distribution in Fog Computing Layer

[2] introduced a mechanism for distribution of tasks which can be of use in this scenario. The procedure involves the creation of two graph structures, the first is known as the task graph and the second one is known as the processor graph, as depicted in Figure 4. The combination of these two is utilized for work distribution in the fog computing layer.

![Figure 4: Work Distribution](image)

4 At-home” Healthcare Monitoring using Fog Computing

The current (at the time of writing this paper) COVID-19 Pandemic has overwhelmed the world’s best healthcare facilities, which has brought to spotlight the importance of home quarantine, or in a general sense, “at-home” monitoring of patients even after this pandemic ends. This can be thought of as a novel area in healthcare technology and fog computing being the state-of-the-art technology needs to be inculcated to build real-time “at-home” healthcare monitoring systems with the goal of reducing the barriers in monitoring patients and providing fast response in the case of an emergency. Moreover, there are many security concerns related to medical IoT devices which need to be addressed via fog computing. The major security concerns are of denial-of-service (DoS) attacks and unencrypted data transmission. In a DoS attack, the device is overwhelmed with numerous requests which makes it stop or become out of order. Eavesdropping by hackers in case of unencrypted transmission leads to confidential information leakage which in turn results in hackers affecting more systems. The biggest tool in such an architecture must be the omnipresent smartphone. Development of Android/iOS applications must take place which can themselves serve as sensors to collect different kinds of data from patients depending on the disease suffered by the patient.
There can be dedicated applications for the numerous departments of medicine such as oncology, neurology, cardiothoracic surgery, psychology, etc. Due to the fact that most people carry their mobile phones with them, the data can be sensed at all times. The architecture for an “at-home” health monitoring system and the pseudo code for data analysis [3] in the fog device is shown in Figure 5 and Figure 6 respectively.

![Figure 5: “At-home” healthcare monitoring architecture](image)

![Figure 6: Pseudocode for data analysis in fog node](image)

In this architecture [4-11], the information collected from the various sensors is transferred to the fog nodes and analyzed there itself. As can be seen in the pseudocode, the fog node compares the gathered data with a threshold value based on the disease suffered by the patient as the critical parameters to be monitored would change from one disease to the other. If the value of the collected parameter is greater than the maximum permissible value, the necessary authorities i.e., the hospitals, paramedical staff, ambulance etc. are alerted which then proceed with the required course of action. Also, in this architecture, the data from fog nodes gets periodically sent to the cloud. However, in the case of an alert being generated, there is a forced update on the cloud due to an emergency situation [12-29].

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