A Cloud-Assisted Internet of Things Framework for Pervasive Healthcare in Smart City Environment

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ABSTRACT

Recently, cloud computing and Internet of Things (IoT) have made their entrance in the pervasive healthcare field in smart city environment. However, the integration of IoTs and cloud computing in healthcare domain impose several technical challenges that have not yet received enough attention from the research community. Some of these challenges are reliable transmission of vital sign data to cloud, dynamic resource allocation to facilitate seamless access and processing of IoT data, and effective data mining techniques. In this paper, we propose a framework to address above challenging issues. In addition, we discuss the possible solutions to tackle some of these challenges in smart city environment.

Categories and Subject Descriptors

C.1.4 [Parallel Architectures]: Distributed architectures

General Terms

Theory

Keywords

Internet of Things, Cloud Computing, Pervasive Healthcare Framework, Smart City.

1. INTRODUCTION

Due to recent advances in information and communication technology, there are a variety of networked sensor-based systems and devices are deployed on the scale of towns, cities, and even countries [1]. It represent an excellent opportunity to support everyday life activities. Such smart environments are actually leading to Smart Cities that can support the activities of their inhabitants to improve quality of life and ensure sustainability in many areas such as healthcare, transportation, sports and entertainment, professional and social life.

Internet of Things (IoT) is the underlying technology to build Smart Cities since they enable everyday entities/objects to communicate and collaborate with each other to provide information and services to users. Recently, IoT technologies have made their entrance in the pervasive healthcare field in smart city environment [2]. The application of the IoT paradigm to the pervasive health field can provide several benefits like tracking objects, medical staff and patient identification, authentication of people and automatic data collection (e.x. continuous monitoring of temporal, spatial and vital sign data of a patient),

However, pervasive healthcare applications generate a vast amount of sensor data that have to be managed properly for further analysis and processing [3]. Efficient management of the large number of monitored data from various IoTs in terms of processing, storing and analysis is an important issue to deal with for its large scale adoption in pervasive healthcare services. Since IoTs are limited in memory, energy, computation, and communication capabilities, they require a powerful and scalable high performance computing and massive storage infrastructure for real-time processing and storing of the data as well as analysis (on-line and off-line) of the processed information under context using inherently complex models to extract knowledge about the health condition of patients.

In this scenario, cloud computing is becoming a promising technology to provide a flexible stack of massive computing, storage and software services in a scalable and virtualized manner at low cost. It can solves most of the IoT issues [4], [5], [6] and also provide additional features such as ease-of-access, ease of-use, and reduced deployment costs [5].

Nevertheless, the research regarding the IoT-Cloud integration for healthcare platform, is still in its infancy, and several technical challenges remain to be addressed to maximize the opportunities. In this paper, we propose a cloud-assisted Internet of Things framework to support pervasive healthcare in smart city environment. We investigate the technical challenges associated with the IoT-Cloud platform for enabling a new generation of advanced, cost-effective and scalable pervasive healthcare services and applications. In addition, we derive the open issues and future directions in the field of CloudIoT for pervasive healthcare.

The rest of the paper is organized as follows: Section 2 describe the related works regarding IoT use in pervasive healthcare. Section 3 presents the proposed IoT-Cloud framework. Section 4 outlines the related challenges of IoT-Cloud platform in healthcare domain. Section 5 presents a case study with the developed IoT-Cloud prototype and finally Section 6 concludes the paper.

2. RELATED WORKS

In recent years, IoT technology is being used in e-health domain due to the development of simplified standard communication protocol between wired and wireless medical devices. In addition, in order to encourage the IoT use in medicine, many manufacturers of biomedical devices, are releasing all the necessary APIs to interact with their products, allowing in this

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way further customizations [7]. However, due to IoT's limited storage and processing capacity, and consequential issues regarding reliability, performance, security, and privacy, a recent trend of integrating IoT with Cloud computing has been emerged.

Current researches [3][7] related to IoTCloud platform for pervasive healthcare scenario focuses on architectural design to realize a health monitoring and analysis system. For example, in [7], the authors propose a framework of IoT-Cloud using VIRTUS middleware for e-health system. It is a publish/subscribe system using XMPP protocol. VIRTUS provides to the system a reliable, scalable andsecure communication channel. In fact, through XMPP, the data are exchanged safely also over internet and there are not data loss, also in case of poor connectivity.

In [3], the authors present a platform based on Cloud Computing for management of mobile and wearable healthcare sensors, demonstrating this way the IoT paradigm applied on pervasive healthcare. Pachube [8] is a real-time data Cloud-based infrastructure platform, which supports the Internet of Things (IoT) paradigm. It is a scalable infrastructure that enables users to build IoT products and services, and store, share and discover real-time sensor, energy and environment data from objects, devices and buildings around the world. Similar platform exists like ThingSpeak [9] and iDigi [10].

However, the aforementioned available systems require the deployment of specific software components for architectures and communication schemes. Furthermore, these systems deal mostly with delivering data to healthcare applications and do not address issues of issues of data management and interoperability issues introduced by the heterogeneous data resources found in modern electronic healthcare systems. The introduction of cloud computing infrastructure may overcome the aforementioned issues. However, still the issue of the reliable transmission of vital sign data, real-time seamless access and efficient processing of monitored data to derive meaningful results, and context-aware patient-centric decision making in a IoT-cloud platform is need to be addressed.

3. Proposed IoT-Cloud Framework for Pervasive Healthcare

Fig. 1 depicts the abstract system architecture of a general IoT-Cloud platform. The system is comprised of five main components: wearable sensors, mobile device, cloud servers, users and display terminals such as Television (TV), personal computer or smart phones.

In the data acquisition end, vital signals (e.x. body temperature, electrocardiograph (ECG), blood pressure (BP) etc), motion and contextual information are collected from wearable and mobile sensors. The collected monitored data are transmitted to the mobile device via Bluetooth and then to the cloud server via Internet or 3G. Here, the mobile devices are act as sensor gateways. The sensor gateways use lightweight interfaces (REST web services) for sending sensor data and retrieving information from cloud.

Cloud servers provide powerful virtual machine (VM) resources such as the CPU, memory, GPU and network bandwidth on demand, for faster management of these data ubiquitously by a variety of interfaces such as personal computer, TV and mobile phones. It can also allow sharing of monitoring data to authorized social networks or medical communities to search for personalized trends and group patterns, letting insights into disease evolution, the rehabilitation process, and the effects of drug therapy.

All the communication between the Cloud infrastructure and the rest of the components is secure by applying appropriate authentication and data encryption mechanisms. ([19]). The proposed integrated system provide various IoT services such as real-time pre-processing, storing, sharing, prioritizing, visualizing, analyzing, summarizing and searching of monitored data as well as acquiring context-awareness to different users such as hospitals, clinics, researchers, or even patients.

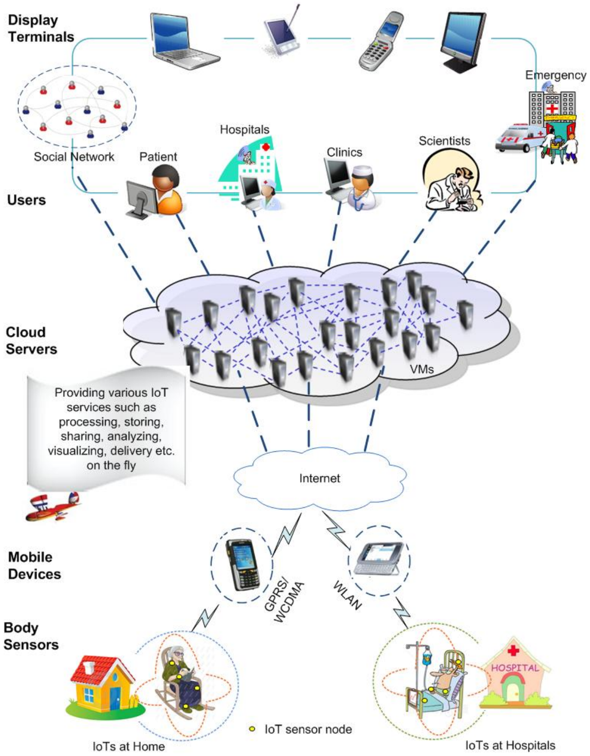

Fig. 1: The proposed general framework for IoT Cloud in Healthcare scenario

The major feature of the proposed architecture is that it can facilitate to build an intelligent (i.e. context-aware sensing capability), autonomous, cost-effective, scalable and data driven pervasive healthcare services platform to realize the long-term monitoring, analysis, sharing, forecasting and management of health status at any time and any place.

4. Related Challenges of IoT-Cloud in Pervasive Healthcare domain

Although the integration of IoT and cloud computing for offers great convenience, there are some technical challenging issues that need to be resolved for its large scale adoption in pervasive healthcare domain. We have identified the following four most important issues as listed in next sections.

4.1 Energy-Efficient and Reliable Communication Protocols

In health IoT-Cloud context, efficient transmission of IoT data to the cloud, timely processing of these huge and streaming sensor data, subject to energy and network constraints and uncertainties, has been identified as one of the main challenges [11]. To support efficient data transmission to IoT-cloud platform, reliable and energy efficient routing protocols need to be developed: Routing protocols are critical for the system to work efficiently. Even though several protocols have been proposed for various domains, none of them has been accepted as a standard, and with the growing number of things, further research is required.

As sensor network is the major enabler of IoT, energy efficient sensing is the main consideration for routing protocols. Although there are some existing routing protocols that can work with minor modifications in IoT scenarios, it is found that existing routing protocols do not satisfy Low Power and Lossy Networks (LLNs) specific routing requirements of IoT in their current form (e.g. optimization for energy saving, typical point-to-multipoint traffic patterns, restricted frame-sizes, limits in trading efficiency for generality) [12].

4.2 Efficient Resource Provisioning

Few studies have been conducted related to effective resource allocation to support various IoT services such as pre-processing, storing, sharing, prioritizing, visualizing, and analysis of monitored data as well as acquiring context-awareness. Resource allocation is challenging in a IoT-Cloud environment due to the diversity of context-aware environments, the range of physiological conditions and the dynamic nature of the resource constraint IoTs [2]. Moreover, the IoT-Cloud platform brings health related media data like image, audio, video along with text data which require strict QoS guarantee. It is cumbersome for a cloud provider to perform over commitment of VM resources for IoT services like pre-processing and prioritizing patients' data, running complex physiological models to analyze the processed information under context, which may have different QoS requirements and unpredictable resource consumption.

Moreover, the irregular spikes and bursts of user activities may complicate the over commitment estimation of VM resources. Furthermore, VM resources need to be allocated not only to satisfy QoS requirements specified by users via SLAs, but also to reduce energy usage. The rising energy cost is a highly potential threat as it increases the Total Cost of Ownership (TCO) and reduces the Return on Investment (ROI) of a cloud provider. Besides, there are costs associated with the use of VM resources, software services, monitoring, accounting, and content delivery in the cloud. In order to attract and retain end-users, it is essential to maintain a high standard of QoS at minimal cost to users, while minimizing the system's own underlying cost and energy.

4.3 Efficient Data Mining Techniques

Pervasive healthcare applications generate data from various IoT (BSNs, WSNs, RFID) environments that are huge in size as well as mixed with dirty and erroneous data. Therefore, extracting useful information or discovering interesting knowledge for patient-centric decision making is a challenging problem. For example, identifying the periodical changes in blood pressure of a patient can be useful information for doctors to provide proper treatment to a particular patient. Additionally, prediction on the change of blood pressure of the patient can be helpful in psro-active healthcare. Thus, discovering patterns having temporal relationship among the readings obtained from the IoTs (i.e. BSNs) can make a great difference in handling/providing care to the user. In other words, discovering shape of occurrence–i.e., whether the pattern occurs periodically, irregularly, or mostly in a specific time interval–can be important criteria for analyzing BSN data.

Nevertheless, finding such interesting knowledge from BSN data by using pattern matching or activity recognition algorithms may not be suitable, mainly because of the involvement of large volume of BSN data, and the requirement of testing and training phases, as most of the activity recognition algorithms rely on classification technique, respectively. Recently data mining techniques are being utilized in discovering interesting knowledge from the BSN data. Therefore, efficient data mining techniques need to be developed for extracting useful knowledge from IoT data. In addition, sometimes IoT-generated data are not always ready for direct consumption using visualization platforms. Therefore, new visualization schemes need to be developed [13].

4.4 Privacy and Security

As healthcare sector deals with patient's personal health information, it is very important to protect privacy information in IoT-Cloud environment. Indeed both its IoT side (i.e., RFID, WSN) and its Cloud side are vulnerable to a number of attacks. In IoT context, encryption can ensure data confidentiality, integrity, and authenticity. However it cannot address insider attacks (e.g. during WSN reprogramming) and it is difficult to implement on computation-constrained devices. Also, security aspects related to Cloud require attention since Cloud handles the economics, along with data and tools. Therefore, more innovative solutions need to be developed in privacy and security aspects of IoT-Cloud paradigm [15]

5. CASE STUDY

To evaluate the proposed cloud-assisted IoT framework for pervasive healthcare, we have implemented a part of it in the context of a simple real time health monitoring system. The system has main two parts: the wearable and mobile sensors that collect and transmit signals like blood pressure, temperature, motion and heartbeat data of a patent through mobile phones to the Internet and then to the cloud infrastructure for storing and managing the data. In addition, we have developed an efficient virtual machine (VM) resource provisioning model in the developed IoT-Cloud platform. The details can be found in [14].

The basic concern of a VM allocation is that a physical machine must have enough capacity for hosting the VMs. To reduce the hosting cost, the number of active physical machines needs be minimized. To save energy or power consumption, most power-efficient physical machines need to be selected. To avoid frequent VM migration, certain amount of CPU capacity needs to be preserved as backup resource for handling workload burst. To reduce the response time, the delay of the services needs to be controlled. According to above considerations, we use two methods to solve the VM resource allocation problem The first method **is** to design a linear programming (LP) model of quantitatively optimizing VM allocation using cost objectives and constraints on the resource utilization condition, CPU utilization, energy consumption and delay of services.

The second approach to solve the VM resource allocation problem is to use different heuristics (FFD, BFD and WFD) []. We studied existing heuristics and modify them to fit our situation. Then, by using appropriate heuristics, we generate candidate allocation schemes and choose the best scheme for real VM allocation. In addition, we will allocate each VM to a host that provides the least increase of power consumption due to this allocation. This allows leveraging the heterogeneity of resources by choosing the most power-efficient servers first.

The VM resource allocation process is performed in a single step using the peak load demands of each workload. Based on the workload demand, the process is dynamically changes virtual machine capacities. However, migration of VMs may be required between physical servers. Thus, when a new service requirement arrives, the system uses the proposed VM allocation algorithm to find the appropriate physical servers. If VM migration is required because of an overloaded state, the system also adopts the same VM allocation algorithm for selecting new physical server.

Several sets of experiments were conducted in the simulation. Firstly, we adopted different request patterns of IOT services/applications in the experiment (i.e. large/small service group at Low/high heterogeneous environment) to measure the cost optimization capability. The number of requests was fixed to 100.

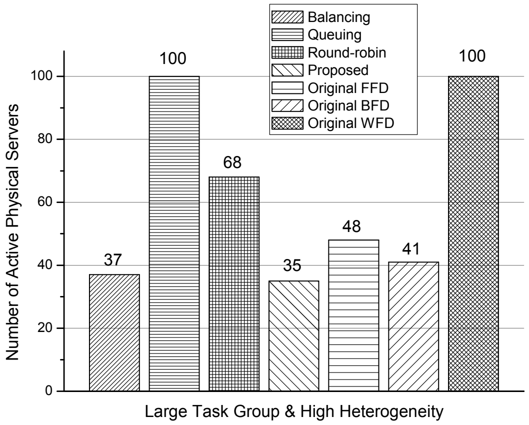

Fig. 2: Cost optimization in large task group at high heterogeneity environment

Fig. 2 shows the simulation results derived from the large task group at high heterogeneity environment. From the results, we have found that our proposed approach outperforms existing algorithms in terms of using less active machines. .

To show the scalability, we varied the number of IoT service requests to test the cost in the large task group and a high heterogeneity environment. Fig. 3 shows the results of the scalability test. When the total number of service requests are increasing our proposed approach demonstrates better scalability than others.

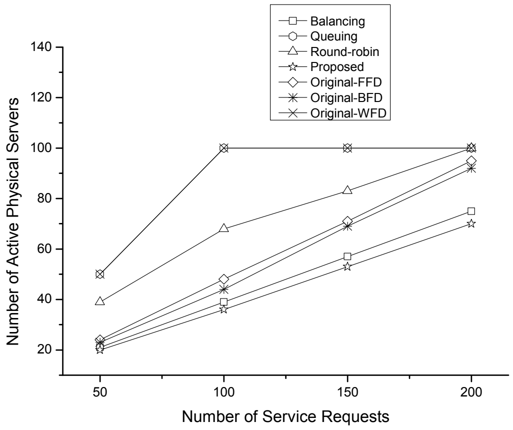

Fig. 3: Scalability Test Results

In addition, to explore the actual response time and QoS success rate in different environments, we did other simulations. Fig 4 and Fig 5 show the results in a high heterogeneity environment. From these figures we can see that our proposed algorithm performs much better than existing ones.

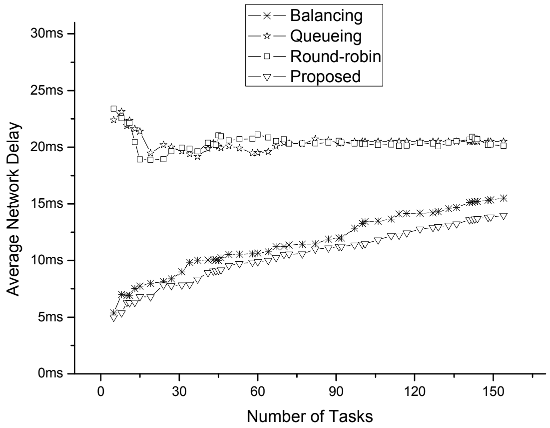

Fig. 4: The response time in high heterogeneity environment

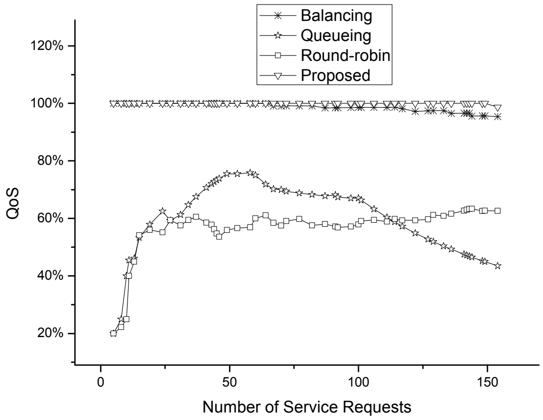

Fig. 5: The Qos success rate in high heterogeneity environment

6. CONCLUSIONS

The paper presents a cloud-assisted IoT framework in pervasive healthcare domain. The proposed architecture is scalable, cost effective and supports interoperability and lightweight access. We also outline the related challenges in IoT-Cloud framework that need to be solved for its large scale adoption in healthcare domain. An initial prototype of IoT-Cloud for pervasive heath monitoring was developed and analyzed. Future work will include the investigation of the framework with real life healthcare data in a larger healthcare settings to justify its scalability, ease of use and cost effectiveness.

7. ACKNOWLEDGMENTS

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