Cloud-based IoT healthcare applications: Requirements and recommendations

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Abstract: Building an architecture for the Internet of Things (IoT) is a complex task, concerning variety of devices and services to be involved in such a system. Healthcare applications impose rigorous requirements on system reliability, quality of service (QoS) and security. In a broad sense m-health represents the delivery of healthcare services through mobile devices, the function of which is to capture, analyze, store and transmit health information from multiple sources, including sensors and other biomedical acquisition systems. This paper surveys IoT for healthcare together with services and applications, security and technologies for promoting the corresponding services. In addition, this paper is going to invoke cloud-based technology and health IoT including Internet of medical things. Next, current standardization activities and recommendations are outlined. Proposals for the future work conclude the presentation.

Key-Words: Internet of medical Things, Cloud-based IoT

1 Introduction

Cloud-based IoT has provided a platform to guarantee distributed-location based services to periodically collecting and broadcasting in various application such as medical healthcare system. On the other hand, cloud computing offers selectable, on-demand computing resources provided as a service from mobile devices to supercomputers. When considering whether to use cloud-based IoT, healthcare actors must have a clear understanding of the unique benefits and risks relative to the purpose and scope of medical practice and healthcare delivery [1, 2].

Internet of medical Things is a challenging environment due to the high number of heterogeneous and potentially constrained network devices and heavy traffic pattern. One of the characteristics of digital medicine is remote access to images and the ability to rapidly share information across geographic areas, compressing time and distance. Ease of cost-effective interactions through secure connectivity across patients, hospitals and healthcare organizations is an important task. Healthcare networks with wireless technologies are expected to support diagnosis and real-time monitoring.

This paper is structured as follows. We start with presenting IoT for healthcare. It highlights services and applications, security as well as appropriate technologies. Next section is going to describe cloud-based technology together with health IoT. Standardization activities and frameworks, together with proposals for future work conclude the presentation.

2 IoT for healthcare

Starting from the potential of IoT-based healthcare technologies, a lot of experiments are carried out worldwide. The obtained results are optimistic in the domain of numerous applications, services and prototypes. Network architecture and platforms as well as interoperability and security are included, too. As initial IoT based healthcare technology, the wireless sensors networks (WSNs) are considered. The IP-based sensor networks using IPv6-based low-power wireless personal area network (6LoWPAN) are adopted [3]. A heterogeneous computing grid collects medical vital parameters such as blood pressure (BP), body temperature, electrocardiogram (ECG), and oxygen saturation [4]. IoT network is formed while transforming into hybrid computing grids the heterogeneous computing and storage capability of static and mobile electronic devices such as medical terminals.

2.1 Services and applications

Services are used to develop applications, and are developer-centric. On the other hand, applications are directly used by users and patients and user-centric. Categorization concerning IoT healthcare services and applications is shown in Table 1.

Table 1. IoT healthcare services and applications categorization.

Services	Applications	
	Single-condition	Clustered-condition
Ambient assisted living Internet of m-health Adverse drug reactions Community healthcare Children health information Wearable device access Semantic medical access Indirect emergency healthcare Embedded gateway configuration Embedded context prediction	Glucose level sensing ECG monitoring Blood pressure monitoring Body temperature monitoring Oxygen saturation monitoring	Rehabilitation system Medication management Wheelchair management Imminent healthcare Smartphone healthcare solutions

Each service provides a set of healthcare solutions. Various types of services with different purposes are presented in Table 2.

Table 2. A set of healthcare solutions.

Services	Healthcare scenario
Ambient assisted living (AAL)	Extend the independent life of elderly individuals in a safe manner, giving them human servant-like assistance in case of any problem [5]
Internet of m-health things (m-IoT)	Mobile computing, medical sensors and communication technologies for healthcare services. M-IoT uses connectivity model that connects the 6LoWPAN with 4G networks for future internet-based m-health services [6]
Adverse drug reaction	The patient's terminal identifies the drug by means of barcode enabled devices [7].
Community healthcare (CH)	Specialized service community healthcare (CH) is used for obtaining collective technical requirements as a package. Community medical network (virtual hospital) integrates multiple wireless body area networks (WBANs) to materialize CH [8].
Children health information (CHI)	IoT service called CHI is developed to address children with emotional, behavioral or mental health problem and their family members.
Semantic medical access (SMA)	IoT healthcare application employ medical rule engines to analyze massive amounts of sensor data stored in the cloud. The wide potential of medical semantics has received attention in designing IoT-based healthcare applications [9,10].
Indirect emergency healthcare (IEH)	Dedicated service called IEH can offer many solutions such as information availability, after notification, post-accident action, and record keeping.
Embedded gateway configuration (EGC)	The EGC service allows for automated and intelligent monitoring. For a medical sensor network based on the IoT a personal mobile gateway is employed [11].
Embedded cost prediction (ECP)	The ECP service is developed in the context of ubiquitous healthcare [12]. A context predictor is applied to IoT-enabled remote health monitoring.

2.2 Security

Iot healthcare domain may be a target of attackers because devices and applications are dealing with private information, presenting healthcare data. In order to obtain the full adoption if IoT for this goals, it is of crucial interest to identify security requirements, vulnerabilities, threat models as well as countermeasures. To achieve corresponding services, the focuses are on confidentiality, integrity, authentication, availability, resiliency, fault tolerance. On the other hand, novel challenging tasks for secure IoT healthcare services include: computer limitations, memory limitations, energy limitations, mobility, scalability. It is well known that threats may originate from both within and outside the network. As for an attacker, he can devise different types of security threats, just to make compromise between existing and future IoT, medical devices and networks.

2.3 Techniques for promoting services

Several technologies such as cloud computing (CC), grid computing, big data, etc., have the potency to promote IoT-based healthcare services.

Cloud computing poses challenges such as high availability, load balancing high performance. Also, there is a possibility of extending cloud computing beyond data centers towards the mobile end-user, providing end-to-end mobile connectivity as a cloud service. The integration of cloud computing into IoT-based healthcare technologies should provide facilities with ubiquitous access to shared resources. In that way, offering services upon on request over the network and executing operations for various needs are realized.

Grid computing is viewed to be the backbone of cloud computing. Including grid computing to the healthcare network, the insufficient computing capability of medical sensor nodes is addressed.

Big data, as the next step in computing, poses numerous challenges to the research community and needs collaborative vision and dialog from various fields including healthcare. It includes huge amount of health data which are generated from medical sensors. Tools for increasing the efficiency of relevant health diagnosis as well as monitoring methods and stores are provided, too.

The question often arises when speaking about network type appropriate for IoT-based healthcare, is an open issue. There are three different types of designing: data, service and patient-service architectures. In the data–centric scheme, the healthcare structure is separated into objects based on captured health data. On the other hand in a service-centric scheme, the healthcare structure is allocated taking into account characteristics that they must provide. Finally, in the patient-centric scheme, healthcare systems are divided according to the involvement of patients they considered for treatment.

3 Cloud-based Internet of medical Things

Cloud-based IoT has provided a platform to guarantee distributed-location based services to periodically collecting and broadcasting. As previously stated, IoT has been widely applied in various application such as medical healthcare system. On the other hand, CC offers selectable, on-demand computing resources provided as a service from mobile devices to supercomputers. When considering whether to use CC, healthcare actors must have a clear understanding of the unique benefits and risks relative to the purpose and scope of medical practice and healthcare delivery. Optimizing case outcomes while maximizing patient safety and the economy, efficiency and effectiveness of care and treatment. Consideration also must be given to the different models of service delivery: infrastructure as a service, platform as a service, and software as a service. Each model includes different requirements and responsibilities. Cloud deployment models (private, public and hybrid) also impact strategic discussions. In that way, they must be considered carefully.

How to design new efficient solutions for next generation mobile technologies with IoT-cloud convergence is crucial issue in healthcare application. According to the functionality, cloud-based IoT can be categorized into static and mobile. Cloud-based IoT has provided a platform to guarantee distributed location-based services by collecting and broadcasting passing service healthcare information.

3.1 Network architecture

Network architecture of cloud-based IoT is shown in Fig. 1 (VANET - Vehicular ad hoc network). It consists of three layers: sensing layer, network layer and application layer.

Mobile IoT users are generally categorized into social groups, since the ones at specific times and locations are always moving in the same platform such as the direction and velocity [14]. Fig. 2 shows one of the possible network model of mobile cloud-based IoT. It is characterized by resource constraints, mobility, self-organization as well as short range communication.

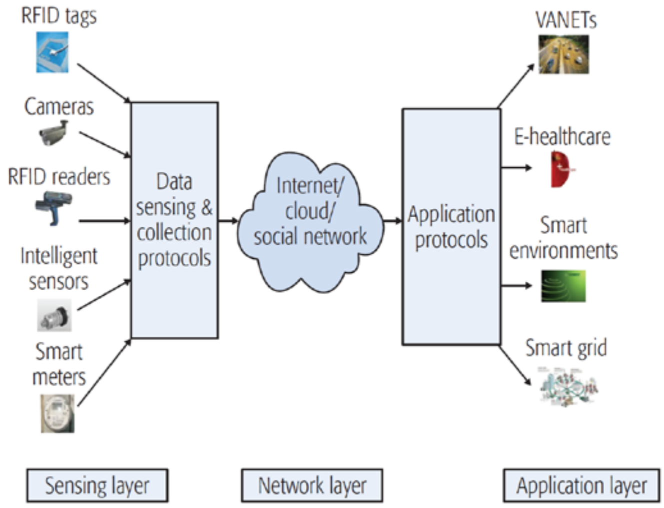

Fig. 1 Network architecture of cloud-based IoT [13].

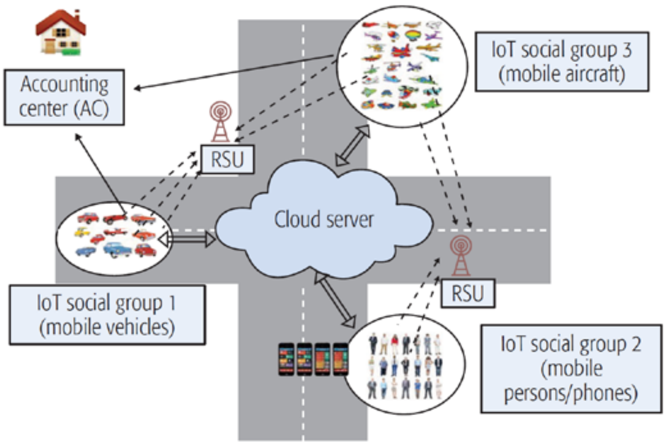

Fig. 2 Possible network model of mobile cloud-based IoT (RSU - roadside unit) [13].

IoT devices are always resource-constrained with the store-carry-and-forward method of packet forwarding only when their storage is available. Computational intensive tasks are intolerable by IoT nodes and must be outsourced to the cloud, both the storage and computational resources. It is reason why resource-constrained property requires protocol design for efficiency especially on the IoT users' node.

As for mobility it should be noted that moving IoT users are categorized into multiple social groups according to their directions, velocity and accelerations. All IoT nodes in each group are in communication range of each other, broadcast their collected content boundless on demand, and share a dynamically updated group key negotiated by all of them. Self-organization means that mobile IoT users frequently collect and broadcast packet bundles within communication range of each other. The cloud is used only when computations of high complexity need to be sent from resource-constrained IoT devices.

Due to both mobility and short-range communication there is no guaranteed connection between the source, and destination in mobile cloud-based IoT. All Iot users constitute a delay-tolerant network (DTN). Packet transmission is realized through cooperation among IoT users and the accounting center. This center is responsible for changing and rewarding. Characteristic comparison between cloud-based IoT and traditional computer networks is shown in Table 3.

Table 3. Comparison between cloud-based IoT and computer networks.

Items	Internet of Things	Traditional networks
Node energy	Constrained	Abundant
Node mobility	High mobility	Static
Architecture	Self-organized	Hierarchical
Communication range	Short	Long
Routing	Intermittent and dynamically constituted	Continuous end-to-end connection
Packet delivery mode	Cooperative, DTN delay-tolerant network type, and need incentive mechanism to stimulate	Guaranteed delivery

3.2 Health monitoring infrastructure

Patient health monitoring system infrastructure is based on integrated cloud computing and IoT technologies. It is a flexible, scalable and energy-efficient remote patient healthcare monitoring system. Generally speaking, the system represents the combination of strong synergy of IoT, cloud computing and wireless technologies for efficient and high quality remote patient health states monitoring [15]. Three layer architecture of the remote health monitoring is shown in Fig. 3.

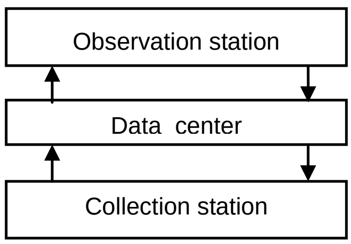

Fig. 3 Three-layers architecture for remote healthcare monitoring.

Each sensor is collection station collects patient data, aggregate it, perform basic processing, and transmit it to a personal server for future processing. The sensors are implantable or attached to everyday objects such as clothes, to gather specific physiological parameters (patient's blood, sugar levels, ECG continuously or on demand, etc). Continuous monitoring is performed when it is needed. During this procedure, sensors continuously collect vital data and send it to the personal server to provide a link between the IoT subsystem and the cloud infrastructure. The personal server receives a stream of sensor data from the sensors. It performs basic data analysis and aggregation generating clear signals, making the data available to the entities subscribed to be notified or pushing the data out to the cloud for further analysis and sharing by healthcare personality. In addition to transferring data from the sensor to the cloud, the personal server can receive a request for specific data from cloud applications or an end user.

In data center, functions that require storing processing and analyzing the collected patient health data from the IoT subsystem are performed. Cloud storage offers benefits of scalability and accessibility on demand at any time from any place. The healthcare provider data center hosts the cloud subsystem, which delivers storage resources and provides computational probability for analyzing and processing of the collected data. The cloud also hosts the middleware system, virtual sensors and application services that allow medical staff to analyze and visualize patient data as well as to identify when events requiring urgent intervention are observed.

In observation station, data driven clinical observation and intervention take place. Doctors, emergency response services, medical research centers and patients have presence. The monitoring center involves the participation of many staff in clinical observation, patient diagnosis and intervention processes. Also, all access requests for patient data are managed by the monitoring center. Authorized user who wants to access the sensor data has to issue a data request to the cloud through monitoring center. If the request data is available in the sensor data storage, the data will be returned to the user.

4 Standardization activities and frameworks

In healthcare, interoperability facilitates the capability to exchange health data between different information technology systems and software. Standards should permit data sharing between providers, diagnostic labs, pharmacies, and patients regardless of the application or vendor. International organizations such as Bluetooth SIG, USB Implementers Forum, IHE, IEEE and HL7 publish specifications, profiles and standards for health data interoperability. The IEEE 11073 Personal Health Data (PHD) family of standards is intended to support interoperable communications for personal health devices, and convey benefits such as reducing clinical decision-making from days to minutes, reducing gaps and errors across the spectrum of healthcare delivery and helping to expand the potential market for the medical devices.

IoT researchers work together with versions m-health and e-health organizations as well as standardization bodies such as the ITIEF (Information Technology and Innovation Foundation), IPSO (Internet Protocol for Smart Objects) alliance and ETSI (European telecommunications Standard Institute) to form IoT technology working groups for the standardization of IoT-based healthcare services. The standardization considers a wide range of topics such as communications layers and protocol stacks. Physical (PHY) and media access control (MAC) layers, device interfaces, data aggregation and gateway interfaces are included, too. One of the advantages of the Internet has been flow of data and trade across borders. This has been facilitated by international agreement of experts, at the same time identifying the most promising technologies to get them adopted on a widespread basis. Maintaining data sharing networks and exchange of trusted information is vital for 5G and the IoT. On the other hand, application developers need open standards and a clear computational architecture in order to have international interoperability.

IEEE 802.16 (WiMax) is a good choice for telemedicine service providers not only in mobile, but also in a fixed environments. The advantages are transmission speed, security, mobility and QoS [16]. Radiology and ultrasound images can be transmitted with significantly reduced delay through the high bandwidth. With a large network capability, some monitoring and diagnostic processes are performed simultaneously. Also, QoS increases the efficiency and reliability of data transmission. The IEEE 802.16 MAC fits with health applications that are designed to be unobtrusive with QoS requirement. In this case, the integration of low rate wireless private area network and a wireless mesh backbone represents wireless solution for delivering medical services in real-time.

IEEE 802.15 (WPAN) wireless personal area network is the standard covering link technologies between data collectors and wireless sensors for healthcare application [17]. ZigBee-based WSNs are for use in acute care hospitals and beyond. A disadvantage is that its low bandwidth of 250 Kbps increases the times it takes to send the same amount of data by up to 4 times compared to Bluetooth Low Energy, which is an avoidable candidate among low-power access technologies.

Body sensor networks (BSN) is a type of WSN. It is deployed on human body to getter physiological parameters for health purposes [18]. Shorter communication range, more limited computation capability and data rate, more sensitive data, higher safety regulation requirements for specific absorption rate, etc., are the unique characteristics compared to majority of general wireless personal area networks. IEEE developed its typical enabling technology IEEE 802.15.6-2012, although it can not meet some desired requirements such as reliability.

5 Concluding remarks

With the rapid development of the IoT and cloud computing, emerging trends and applications of cloud-based IoT in healthcare become evident. The question arises is the integration of cloud-based IoT in the next generation healthcare system. A series of challenging open research issues are identified such as: access control, data confidentiality, location privacy, privacy-preserving outsourced data mining, the huge volume of computational complexity which still significantly impedes its wide applications on resource-constrained users.

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