Some new services and network architectures and educational results in the Internet of Medical Things (IoMT)

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Abstract— Starting from the potential of IoT-based healthcare technologies, a lot of researches are carried out worldwide. The obtained results are optimistic in domain of new services and applications, network architecture and platforms as well as standardization frameworks for interoperability. However, the IoT remains in its infancy in the healthcare domain. Taking into account trends, an analysis of mobile health (m-health) in context of IoT as well as how emerging 5G network technology will influence on real-time healthcare services, is of wide interest. The motivation is to expand the potential of core IoT technologies for the further developments. This paper highlights future research on IoT healthcare based on a set of open issues and educational challenges.

Keywords— m-health, Cloud-based IoT, 5G mobile networks

I. Introduction

Internet of medical things (IoMT) is the collection of medical devices, services and applications that connects to healthcare ICT systems based on telecommunication networks. The emerging ecosystem has a very complex architecture. IoMT devices connected to cloud platforms on which captured data can be stored and analyzed. Examples of IoMT include tracking patient medication orders, remote patient monitoring of people with chronic conditions, and patients' mobile health (m-health) devices. The use of mobile devices, sensors and remote monitoring equipment represents an advancement for patients receiving data, imaging, diagnosis and finally treatment using digital technology. According to the WHO (World Health Organization), e-health represents the transfer of health resources and healthcare by electronic means. It includes the procedure to delivery of health information through the Internet and using telecommunication devices [1].

In this context, the primary goal is to research technologies that will provide integration and intercommunication between different devices through the Internet [2, 3]. As a result, it is expected that healthcare services will change soon. In connection with this trend in developments, e-health should set requirements from the view point of data acquisition, access control, security and safety. It should be noted that an e-health system implementation is not only a technical, but also a political and administrative challenge with numerous regulative measures such as standards, regulations and economical efficiency.

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Evaluation of an IoMT system on a large scale of requirements is of great significance. In a broad sense mobile health represent the delivery of healthcare services through mobile devices, the function of which is to capture, analyze, store and transmit health-information from multiple services, including sensors and other biomedical acquisition systems. As for the activities in the area of healthcare services based on wireless sensor networks (WSN), they can be treated as initial research efforts toward the IoT [4].

IoT and healthcare have got valuable application requirements in the emerging 5G networks, creating a new era of communications, allowing people to have real-time health services. Healthcare applications impose rigorous requirements on system reliability, quality of service (QoS) and security. In 5G networks it will be significant to deal with business models, ICT-driven network architecture, heterogeneous access, together with enhanced privacy protection.

Generally, services and protocols for IoT frameworks require slight modification when healthcare scenarios are taken into account. Research trends in IoT-based healthcare include network architectures and platform, new services and applications, interoperability and security

The goal of this paper is to emphasize some research trends in IoT-based healthcare. To achieve before mentioned objectives, the subject is divided in two parts. At first, mobile healthcare in the context of IoT is presented related to devices and networks in such a way to prepare the scenario for new applications and services as well as security in the corresponding domain. The second part demonstrates the influence of 5G mobile network technology on healthcare including benefit of machine-to-machine and device-to-device communications as emerging solutions.

II. Mobile health in the context of IoT

Mobile health (m-health) refers to the use of medical devices equipped with sensors and communication devices.

The goal is to collect health data from patients in real-time and to store them to network services connected to the Internet. The doctors are using m-health data to monitor, to diagnose and treat the client. Also, integration of mobile health devices in the client environment provides capabilities to predict different health anomalies in real-time [4]. Mobile health technology founds for the key personal healthcare services in the near future. The Internet of m-health (m-IoT) is mobile computing, medical sensors, and communications technologies for health services [5].

A. *Sensing layer*

Mobile health devices use a huge amount of data. The devices are connected to IoT servers to store, transmit and receive data. Some main characteristics for m-health devices are as follows: compact and easy-to-wear, IP enabled and wireless connectivity, low power consumption. For example, there are many m-health devices with various size and working capabilities. On the other hand, each m-health device has IP address as an unique identifier to enable the corresponding device to transmit and receive data over heterogeneous network.

The function of connected devices is to support the process of monitoring, diagnostic and patients treatment taking into account low power, low cost, physical size as well as easy of use [6]. Low power consumption is required because these devices are supposed to work for long period of time delivering at the same time longer battery life as much as possible. In order to save hardware features and to make intelligent power management decisions, there exists a tight integration of software to the hardware in mobile devices.

Wearable devices (smart watches, fitness monitors) have a set of features for the IoT architecture. Using smartphones and tablets devices can be seamlessly connected on a wider access network through ad-hoc and wireless networks [7].

The main advantages od wireless devices connectivity are ease of maintain and deploy as well as readily upgradable to latest standards. Their attraction lies in cost reduction, measurement objectivity, and ease of use. The main challenges are as follow [8, 9]: i) home monitoring product lack standard and aggregation, ii) gap between tracking and persistent behavior change, iii) clinics are slow in adopting new technologies, iv) reduction in overall cost of healthcare not yet proven.

B. *Network layer*

IoMT topology refers to the arrangement of different elements of network. The principal factor in designing IoT topology is identify associated activities and roles in medical services, from the view point if service providers (Table 1). The architecture refers to an outline for the specification if the IoT healthcare network's physical elements, their organization and working way. It can be considered as a complete mesh networking system with Internet connectivity.

Table 1. IoMT network.

Topology	Architecture	Platform
physical configurations, application scenarios, activities, and use-cases	software organization of the system as a whole and hierarchical model	library, framework, and environment

IoT platform refers to both the network platform model and the computing platform. The open issue is the importance of standardizing interfaces toward the design of an open platform [10]. In order to establish a cooperative ecosystem, three categories of interfaces are shown in Fig. 1, including hardware and software interfaces, health data formats (electronic health record), and security schemes.

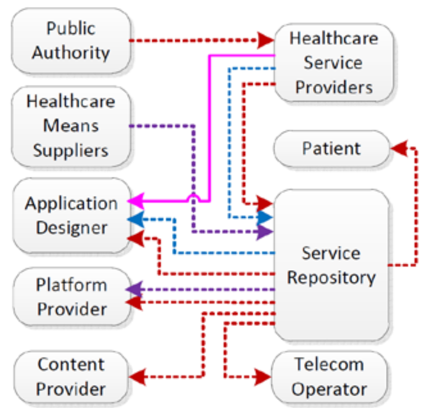

Fig. 1 An example of open-platform IoMT [8].

C. *Application layer*

World Health Organization (WHO) defines mobile health (m-health) as the medical and public health practice supported by mobile devices such as mobile phones, patient monitoring devices, and many other wireless devices. Generally, healthcare is being shifted from the centralized model to the distributed model. Thus, m-health technology will be the key of personal healthcare services in the future. In that way m-health offers the solution for a problem how to access the right information where and when needed in dynamic and distributed healthcare organizations. The final goal is to decrease medical errors in order to improve the efficiency of health services and at the same time a reduce operating costs.

Generally, services and protocols for IoT frameworks require slight modification when healthcare scenarios are taken into account. 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 IoMT services and applications is shown in Table 2.

Table 2. IoT healthcare services and applications categorization [9].

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

Each service provides a set of healthcare solutions. Various types of services with different purposes are presented in Table 3.

Table 3. Variety of IoT healthcare services providing a set of healthcare solutions.

Services	**Healthcare scenario**
Ambient assisted living (AAL)	An IoT platform powered by artificial intelligence with the purpose is to extend the independent life of elderly persons in their place of living in a safe manner [11]
Adverse drug reaction (ADR)	The patient's terminal identifies the drug by means of barcode enabled devices [12] to verify whether it is in accordance with electronic health record.
Community healthcare (CH)	Community medical network (virtual hospital) integrates multiple wireless area networks to materialize specialized CH service [13] and healthcare monitoring in covering area.
Semantic medical access (SMA)	With medical semantics on the top of the IoT healthcare applications employ rule engines to analyze massive amounts of sensor data stored in the cloud [14].
Embedded gateway configuration (EGC)	The EGC service allows for automated and intelligent monitoring based on the IoT a personal mobile gateway [15].
Indirect emergency healthcare (IEH)	In many emerging situations, dedicated service IEH can offer many solutions such as information availability, after notification, post-accident action, and record keeping.
Embedded cost prediction (ECP)	The ECP service is developed in the context of ubiquitous healthcare [13].

An example of IoMT-based healthcare solution is shown in Fig. 2, with the way a heterogeneous computing grid collects sensor data such as blood pressure, body temperature, electrocardiogram (ECG), oxygen saturation, etc. Here, the heterogeneous computing and storage capability of static and mobile devices (laptops, smartphones, medical terminals) are transformed into hybrid computing grid.

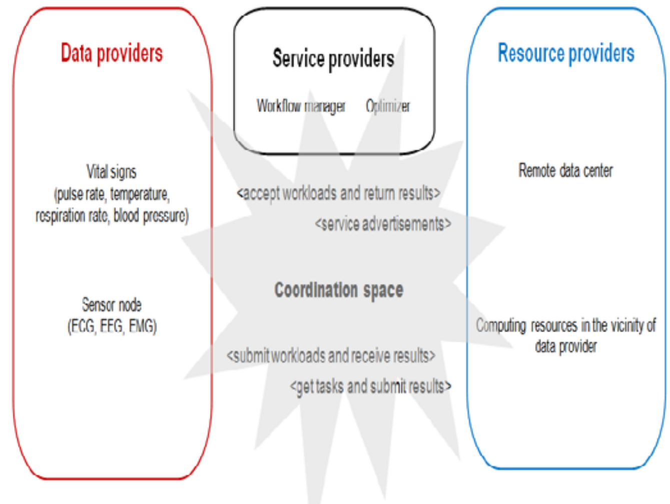

Fig. 2 An IoMT conceptual solution.

D. Standardization issues

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

From a standardization perspective, the IoT can be viewed as a global infrastructure, enabling advanced services by interconnecting (physical and virtual) objects based on evolving interoperable information and communication technologies (ICT). The success of the IoT will depend strongly on the existence and effective operation of global standards. The research projects, standardization initiative and industrial activities are outlined in [16]. There are already many standardization activities related to the IoT, covering broad research areas: wireless and cellular technologies, networking protocols, emerging applications, media-centric IoT. What is needed, therefore, are a harmonization of standards and effective frameworks for large scale deployment. Several contributions to the full deployment and standardization of the IoT paradigm come from the research community. Among them, the most relevant are provided by the European Commission and European Standards Organizations (ETSI, CEN, CENELEC, etc.), by their international counterparts (ISO, ITU), and by other standards bodies and consortia (IETF, EPCglobal).

The main challenges for the IoT and 5G are maintaining data sharing networks and exchange of trusted information. On the other hand, application developers need open standards and a clear computational architecture in order to have international interoperability.

E. Security issues

IoT healthcare domain may be a target of attackers because different devices and applications are presenting private information. On the other hand, it is patient’s right to control the access of personal health data. Confidentiality, privacy and security are the main issues from this point of view. Confidentiality refers to the obligation of professionals who have access to patient records or information to hold that health information in confidence. Privacy is the right to make decision about how personal information is shared, while security is dedicated to physical and technical tools to protect health data [17]. Anyway, it is of importance to balance confidentiality, privacy and security with the system availability (Fig. 3).

In a mobile health system data are stored and have access via Internet. Mobile health data and devices have to use HIPAA (*Health Insurance Portability and Accountability Act*) standard for protecting sensitive patient data. It means that dealing with health data protection requires that all physical, network and process security measures are applied.

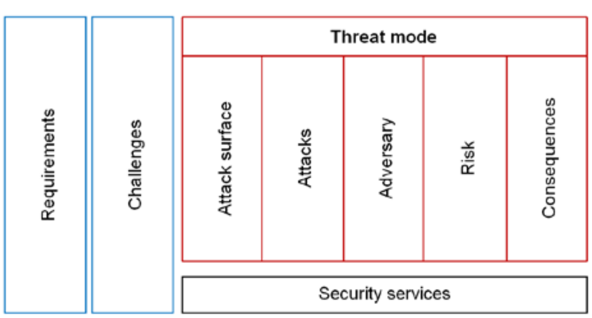

Fig. 3 Research challenges in IoMT security.

To facilitate the full adoption of the IoT in the healthcare domain, open challenge is to identify and analyze distinct features of IoT security and privacy from the healthcare perspective are as follows: security requirements, vulnerabilities, threat models, and countermeasures.

III. Influence of 5G mobile network technology

Emerging 5G capabilities could generate improvement in healthcare providing many scenarios. Key 5G capabilities for m-health are: bandwidth, very low latency, network capacity, scalability, massive number of devices, long battery lifetime, reliability, resilience and security. Connected devices, fast and intelligent networks, back-end services and extremely low latency are the main characteristics of 5G.

As a challenge, IoT devices have varying capabilities and data demands, while 5G network needs to support them all. As most desktop computers or tablets lack sufficient storage, the resolution is found in a cloud which provides the extensive storage capabilities. The open issues in 5G networks are as follows: IT-driven network architecture, heterogeneous access and enhanced privacy protection.

A. Enhanced mobile broadband

The primary challenge is to improve the data rate and traffic capacity in the 5G network using more spectrum. Very high transmission rate on the order of Gbps enables streaming of high resolution medical images (UltraHD). One of the main advantages in digital medicine is remote access to images and to share information across areas, compressing time and distance. This fact reduces health disparities and helps to bridge urban/rural difference in a position to access a global network of medical service. Moreover, 5G networks can reduce communication latency to less than 1ms. Generally, robotic systems have got an inherent latency of approximately 100ms [18].

The recent 3GPP architecture composed of network functions (NF) and reference points connecting NFs are shown in Fig. 4. User equipment (UE) is connected to either RAN or access network (AN) as well as access and mobility function (AMF). RAN represents a base station using new RAT (Radio Access Technology) and evolved LTE while AN is a general base station including Wi-Fi access.

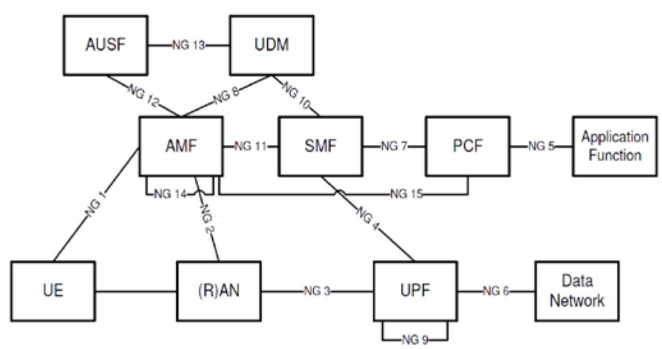

Fig. 4 NextGen architecture and reference points.

The NextGen access and core networks consist of various network functions. There are seven NextGen Phase 1 core NFs: access and mobility function (AMF), session management function (SMF), policy control function (PCF), application function (AF), authentication server function (AUSF), user plane function (UPF), and user data management (UDM) [19].

B. Mobile cloud

When deciding whether to use cloud computing, a clear understanding of the benefits and risks relative to the purpose and scope of healthcare delivery has to be taken into consideration [20, 21, 22]. Cloud computing poses challenges such as high availability, load balancing high performance. Also, there is a possibility of extending cloud computing beyond data centres towards the mobile end-user, providing end-to-end mobile connectivity as a cloud service.

In mobile health, scalability is important, when taking into account the fact that the network must allow for a seamless increase/decrease of nodes without affecting network operation. The support of massive number of devices is of importance because of low-cost or low-complexity with non-delayed and non-sensitive data. Also, there is a need for a scalable and flexible network with wide coverage.

IoT devices are always resource-constrained and comply with the store-carry and forward (SCF) method of packet forwarding only when their storage is available in delay tolerant network (DTN) (Table 4). Computationally intensive tasks are intolerable by IoT nodes and must be outsourced to the cloud, both the storage and computational resources of which are assumed to be abundant. Therefore, the resource-constrained property requires lightweight protocol design for efficiency and practicability, especially on the IoT users' ends.

Table 4. Characteristics of cloud-based IoT.

	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

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, cloud computing offers selectable, on-demand computing resources provided as a service from mobile devices to supercomputers. When considering whether to use cloud computing, 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 (IaaS), platform as a service (PaaS), and software as a service (SaaS). Each model includes different requirements and responsibilities. Cloud deployment models (private, public, hybrid) also impact strategic discussions. In that way, they must be considered carefully.

C. Massive M2M and D2D type communications

IoT and M2M are expected to be two extremely important drivers to 5G networks. Machine-to-machine M2M technology opens the doors to a new possibilities in the medical field and especially m-health. Also, device-to-device (D2D) technology enables devices to be connected directly with or without the need for control or network assistance. In that way D2D becomes an excellent substitution for devices to communicate when the conventional cellular link is not available. In this case, connectivity between health stuff and medical devices is of a very high priority. One challenge with these applications is the massive number of terminals, which leads to the necessity of extremely high-dense networks. Thus, two important requirements to support IoT applications are scalability, and high connection density.

By using a heterogeneous communication network, M2M communications allow interconnection between devices without the human action [23, 24]. This scenario is related to sensor networks and several non-critical V2V (vehicle to vehicle) communications. The primary requirements associated with this scenario are connection density and energy efficiency. For example, a connection density equal to 106 devices/m^2 is specified, and it is affirmed that the energy efficiency must be 100 times better than the energy efficiency in 4G networks. It is specified that certain devices require a 10-year battery life.

The use of D2D for direct communication permits that multiple D2D links simultaneously share the same bandwidth, thus increasing the traffic capacity of the cell. Additionally, the direct communication approach can increase the SNR (when compared with the communication via a base station), which increases the capacity of the link, or can save energy by decreasing the power transmission. Finally, D2D direct communication reduces the latency of the radio link. Device-to-device communications can be used in two different ways. First, one terminal cooperates with another terminal in such way to improve the quality of the communication between the terminal and the base station; this approach is denominated cooperative communications. In the second way, one terminal can establish communications directly with another terminal without the participation of the base station [25]. The use of D2D for cooperative communication can result in several benefits: improved channel reliability, improved system throughput, seamless service provision, operation cost reduction, and improved energy efficiency.

IV. Education

Research challenges are distributed in almost all aspects of solutions, ranging from the enabling devices to the top level business models. So IoMT educational space shows a cross-layer and multidisciplinary pattern. We propose an IoMT curriculum fusion of expertise in bioengineering and medical life sciences based on *Classroom* e-learning platform (Fig. 5).

The Internet services http://classroom.google.com aim to simplify creating and distributing teaching materials. In April 2017, it became available for personal *Google* user to create and teach a class. In our open online course, we combine services: *Drive* for assignment creation and distribution, *Docs*, *Sheets* and *Slides* for writing, *Gmail* for communication, *Calendar* for scheduling. Students are invited to classes through a private code. IoMT class creates a separate folder in the respective user's *Drive*, where the student can submit work to be a graded by a lecturer. Mobile *Android* apps let students access information offline. Lecturers monitor the progress for each student, and after being graded, teachers can return work, with comments, for the student to revise and improve the assignment. Lecturers post assignments and announcements to a class stream, where students can comment. IoMT blended-learning course combines online teaching materials with traditional in-pearson instruction in an optimized modus.

V. Concluding remarks

To connect the healthcare world on creative ways, there are many opportunities. Internet of Medical Things (IoMT) enables machine to machine interaction and real time intervention solutions which will radically transform the healthcare delivery, affordability and reliability in near future.
By providing the individual data driven treatment, IoMT will promote personalized care and high standard of living.

For the realization, it is expected that research work has to be done to facilitate end-to-end system. From this point of view, the paper contributes by: providing a survey of some research trends in mobile healthcare services and applications in the context of IoMT, offering insights into security issues surrounding IoMT domain, supporting researches in integrating 5G technology innovations in healthcare system including m-health, cloud-based Internet, network architecture and platforms, emphasizing the significance of M2M and D2D communications for mobile health solutions.

The final goal is to address the transformations of healthcare technologies through the IoT innovations. In such a manner the way for discussing the future mobile networks and services requirements will be paved.

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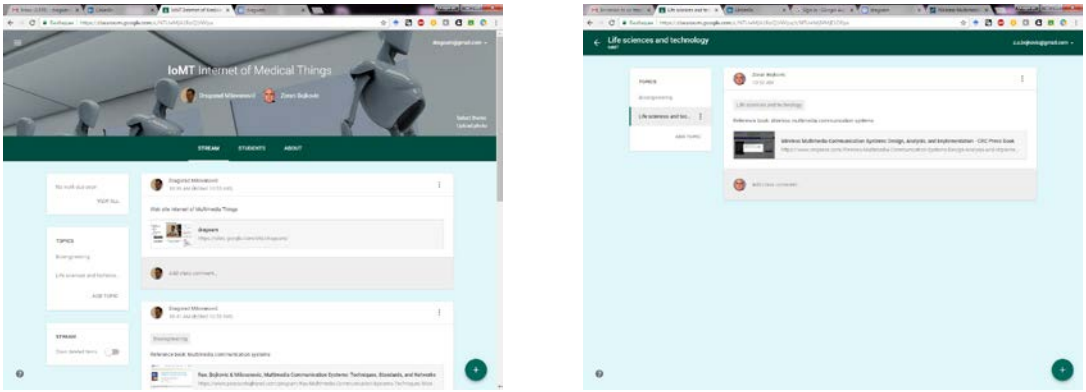

Fig. 5 IoMT *Classroom*: a) an bioengineering lecturer's view, b) a medical life science and technology lecturer's view.