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Senior Design Project Report

**MOBILE DEVICES IN APPLICATIONS FOR
HEALTHCARE:
SYSTEMS AND TECHNOLOGY**

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Abstract

Spanish

Actualmente, la evolución de las comunicaciones inalámbricas y de las tecnologías de red permite el acceso a servicios médicos de manera remota desde una gran variedad de dispositivos móviles. Este nuevo contexto técnico-sanitario se conoce como m-Health y, junto con otras tendencias de nueva aparición sector como el historial clínico electrónico (HCE), podría suponer una auténtica revolución en el sector de la salud y, más concretamente, en el tratamiento y seguimiento de enfermedades crónicas.

En este proyecto se exploran las posibilidades ofrecidas por e-Health y, más detalladamente, por m-Health para la gestión de enfermedades crónicas por parte del propio paciente desde un punto de vista técnico, haciendo especial hincapié en la estructura de comunicaciones necesaria. Para ello, se describen las tecnologías, arquitecturas y dispositivos disponibles con capacidad suficiente para satisfacer los requisitos establecidos por una enfermedad crónica concreta: diabetes.

Atendiendo a estas consideraciones, se propone un sistema para el tratamiento de la diabetes basado en las oportunidades de las tecnologías inalámbricas actuales.

Por último, el texto concluye con una serie de observaciones sobre la situación actual de m-Health y sus futuros retos.

English

At present, the evolution of wireless communications and networking technologies allows the access to medical services from a great variety of mobile devices remotely. This new technical-medical context is known as m-Health and, along with other emerging health trends like electronic health record (EHR), could be a revolution in the health sector and, more specifically, in the treatment and monitoring of chronic diseases.

This project will explore the possibilities offered by e-Health and, in more detail, by m-Health for the self-management of chronic diseases from a technical point of view, with particular emphasis on the necessary communications structure. To do so, we describe the technologies, architectures and devices available with sufficient capacity to meet the requirements of specific chronic disease: diabetes.

In response to these considerations, we propose a system for the treatment of diabetes based on current wireless technologies opportunities.

Finally, the text concludes with a series of observations on the current status of m-Health and its future challenges.

1.- Introduction

At present, healthcare is facing several problems of great importance at every level, from primary care to emergency services, not forgetting the care of chronic diseases.

The major problem is the increase of the expenditure inherent to actual healthcare model which often places a great burden on national economies. The interest is focused on improving the use of available resources at each facility to provide services in the most efficient possible way.

From a strictly sanitary point of view, all services are centered around medical facilities, where the patient must go in case of disease or for receiving treatment or advice from their physician. This situation is especially uncomfortable for those who suffer from chronic or long lasting diseases.

As a consequence of this situation in order to overcome these obstacles, new models for healthcare seem to be needed. In this sense, major technological advances which are occurring simultaneously may be of particular interest for the health sector.

One of them is the the remarkable improvement of wireless sensor networks (WSN). A new generation of low-power, long-life wireless sensors with improved capturing and processing capabilities, among other features, along with new versions of short-range wireless technologies, like Bluetooth LE or ZigBee, enable the integration of WSN in some medical treatments for monitoring purposes or remote diagnosis and care.

The worldwide expansion of mobile networks and the continuing evolution of mobile devices may cause another breakthrough in health delivery systems. These technologies capacitate remote connections practically at any time anywhere increasing the reach and flexibility of typical health services.

Some other popular concepts in technology like M2M communications, Cloud computing, Big Data or the Internet of Things will probably have a significant role in the future models for health services.

This project aims to assess the opportunities arising from the convergence of these new technologies in the health sector for the specific case of the chronic diseases management, more concretely, diabetes.

To this end the text is organized in three main blocks: technology, chronic disease and discussion. Each of these blocks contains the following topics:

Technology block encompasses sections 2 to 5. Section 2 presents an overview of ecosystem eHealth, its possibilities and the obstacles to its deployment. Section 3 focuses in mHealth, a branch within eHealth, highlighting its key features in relation to health issues. Next, sections 4 and 5 deal with the technological aspects and communication architectures supporting mHealth.

Chronic disease block is constituted by sections 6, 7 and 8. Section 6 defines chronic disease and shows the special needs required for its management. Section 7 introduces the concept of remote healthcare and section 8 addresses these issues from the point of view of diabetes.

Finally, the discussion block. Section 9 will propose a system to manage diabetes based on the opportunities of mobile devices and systems exposed in the technology block in order to meet the specific requirements expressed in chronic disease block. Next, section 10 will show some of the components that can be part of mHealth diabetes solutions and current systems available nowadays. Section 11 will conclude this project with a series of observations and recommendations.

2.- e-Health overview

e-Health involves the application of the latest information and communication technologies (ICT) to care delivery. The term can encompass a range of services or systems that are at the edge of medicine/healthcare and information technology, including for example (See Figure 2.1):

- Electronic health record (EHR): enables the communication of patient data between different healthcare professionals (general practitioners, specialists etc.).
- Telemedicine: physical and psychological treatments at a distance.
- m-Health: includes the use of mobile devices in collecting patient's health data in real time, allowing this information to be accessible by doctors, researchers, and patients themselves.
- Remote patient monitoring (RPM): makes it possible to measure vital signs at home, for example.
- Mobile patient monitoring (MPN): could be seen as the combination of RPM and m-Health. MPN employs mobile computing, wireless communications and networking technologies to monitor patients outside the medical centres and away from home.

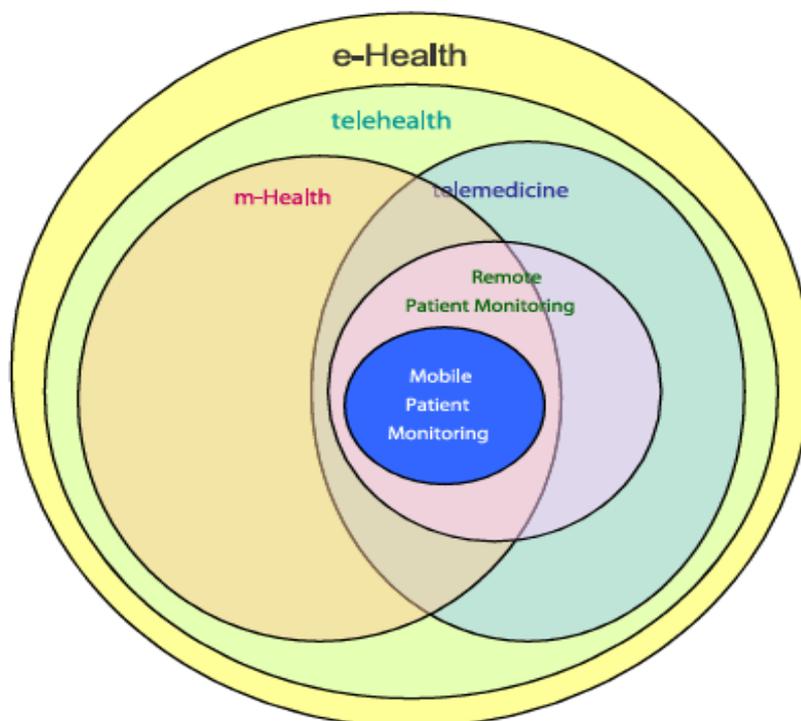


Figure 2.1: Relationship between some of e-Health paradigms [1]

Nowadays, patients need to go to a clinic or a hospital for medical care. Those living in rural areas or in regions with inadequate health services have to either travel long distances or accept substandard medical services. Patient data stored in the files of a primary care physician are not usually readily accessible by specialists, pharmacies, hospitals or labs. These are some barriers to receiving optimal health care. e-Health may be the solution in order to overcome these problems.

Healthcare sector will evolve towards individualized, preventive medicine that is time and place independent if e-Health development succeeds. In Figure 2.2 the expected changes in medicine due to the outburst of e-Health solutions are shown.

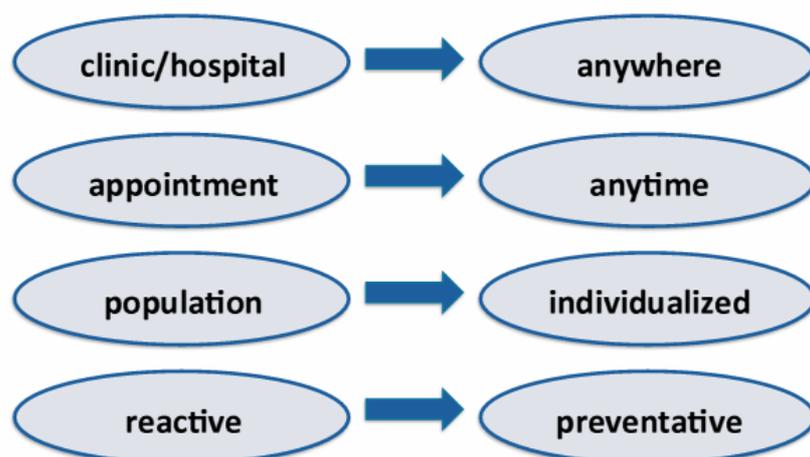


Figure 2.2: e-Health changes in medicine [2]

Patients may be able to inform their physicians from virtually anywhere at anytime and caregivers may deliver individualized attention remotely. Therefore e-Health will improve both patients' lifestyle and caregivers' work and productivity.

Moreover, e-Health is expected to reduce medical costs by developing preventive treatment in place of existing reactive treatments as well as by reducing errors.

Although it would be desirable to take advantage of all these benefits, e-Health is a great challenge as it involves major changes in the core of the health sector.

2.1.- Ecosystem of e-Health

For any e-health initiative to be successful, it must be considered as an ecosystem with many interconnected parts, rather than just a technology infrastructure. According to [3] they can be grouped into the following categories:

- Governance

National governments should create new policies to oversee, regulate, and manage e-Health programs in order to improve health sector efficiency. This supportive legislation must consider wisely security and privacy.

- Stakeholders¹

Stakeholders are key actors in both the design and the success of any e-Health program. Each of them has different objectives and motivations for participating in e-health programs.

- Financing

The appropriate funding for the implementation, maintenance and ongoing operation of those e-Health programs must be ensured. Governments will have to consider the kind of reimbursement model needed for each specific e-Health solution, while favoring the stakeholders with some type of incentives.

- Technology

The technology used for the implementation of an e-Health system is another critical decision. It will determine the type of data and communication supported, and the necessary infrastructure in order to take full advantage of the e-Health initiative. A bad choice in this part would suppose serious problems for the viability of the project.

- Services

e-Health services should use the available or planned technology infrastructure in order to satisfy patients' needs, which can vary locally. Some recent examples are:

- National electronic health records (NEHR) that can manage patient data records and offer alerts on personal drug allergies and drug side effects.
- Disease management systems that gather, store, transmit, and analyse information on chronic diseases such as diabetes.
- Ambient Assisted Living (AAL) services such as monitoring the vital signs of elderly people or chronic patients in home environments.
- Integrated disease surveillance which are platforms for public health agencies to detect unhealthy syndromes and coordinate responses.

¹ *Stakeholder* refers to any person, group, organization, member or system who affects or can be affected by an e-Health project

All five dimensions of the ecosystem are deeply connected. For example, technology assets need to be deployed before services can be offered, and sustainable financing is not possible without appropriate regulatory practices. Figure 2.3 shows the ecosystem and its relations adapted to m-Health space:

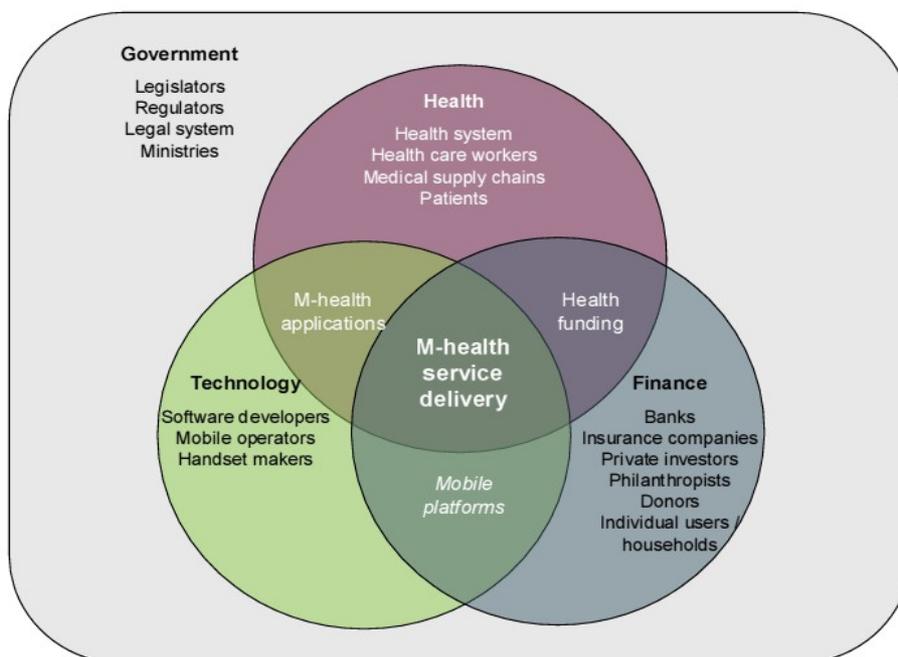


Figure 2.3: The ecosystem for m-Health [4]

Any e-Health intervention must be designed based on specific problems and conditions in accordance with current legislation and available technology in each location. The key for final success is to approach any new e-Health initiative in a systematic manner using all five parts of the framework in order to reach sustainability and efficiency as indicated in Figure 2.4:

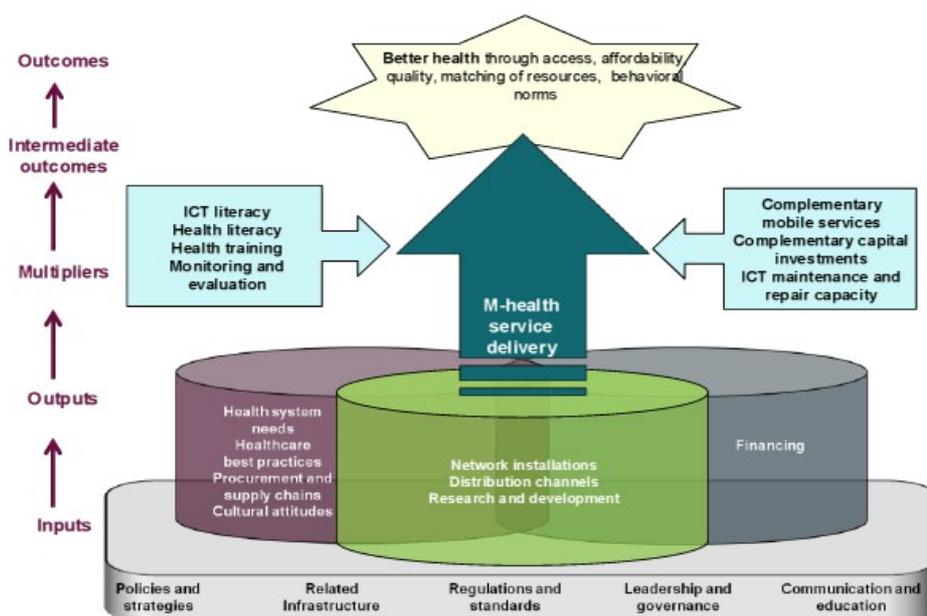


Figure 2.4: Framework for m-Health outcomes [4]

In this sense, ICT stresses the role of unified communication and the integration of telecommunication environment in order to provide a full solution that suits patients' needs.

2.2.- Obstacles

However, e-Health still faces divers obstacles that affect the rate of adoption of e-Health initiatives. Some of them are explained by financial aspects related to investment and profit. Others stem from the lack of regulation or the availability of the necessary technology. Even some reeducation is required for health professionals and patients. The most common e-Health obstacles are briefly detailed below [5]:

Economic

Considering the fast evolution of the technology sector is not surprising that one of the main risks of any e-Health solution is obsolescence. The solution to avoid this risk consist in investing money periodically in the upgrade and maintenance of the systems. This can increase the costs of the e-Health initiative.

Another economic obstacle has to do with the reimbursement. Some e-Health programs, mostly the ones used for prevention, which is a great application opportunity for e-Health, are not easily reimbursable.

Finally, more demonstrated outcomes showing the efficacy of successful e-Health solutions seem to be needed for convincing investors of the viability of the sector. The economic impact of increased investment will achieve an improvement in the quality of the services provided by these solutions.

Legal

To be deployed, every e-Health solution must obtain a certificate of approval for a particular medical problem. Each country has its own regulatory processes and therefore the time and costs associated to get the approval varies.

Technological

Development and growth of e-Health mainly relies on the availability of the technologies suitable for each application. These technologies are at different stages, namely:

- Technologies currently unavailable.
- Available technologies: the ones in the R&D phase or not tested for health sector.
- Proven technologies: These technologies are on the market, either as complete systems or as components.

Proven technologies and available technologies are the cornerstone on which rests the success of e-Health.

Educational

Health care providers need to know the right time and how to introduce the solution to the Health community. Physicians will probably require some training to get familiar with the new system and patients will also need to become aware that they play an active role in both the prevention and the care of their own illnesses. The latter is particularly important in rural areas and in underdeveloped communities, as well as for chronic diseases.

2.3.- Technological problems

Technical problems associated with the special nature of the data managed in health sector as well as with the characteristics of the technologies needed could also affect the e-Health expansion. From the standpoint of the technology and data management, the main problems are the following [6]:

Interoperability

Considered as e-Health's primary goal, interoperability means that any e-Health system must provide data in a format compatible with the rest of the components of the system and with other systems requiring this data, regardless of the communication protocols or the manufacturers. This compatibility allows applications or services to communicate and transfer data ensuring security and proper performance.

For example, a system using radio devices must be able to operate the same way independently of the country in which it is deployed and its restrictions. Standardization is needed to obtain interoperability. However, this is a field that requires many efforts as there are still manufacturers developing and selling products based on different proprietary protocols and not compatible with other solutions.

Security

Security is a very sensitive issue in health sector. Both devices and communications must be made secure in order to protect patients' personal data.

On the devices side, they should be immune to some attacks and at the same time not represent a threat to either the user or the system around.

Moreover, communication security in the e-Health sector is of utmost importance due to the nature of the transmitted data. Security is obtained through the checking of the following attributes:

- Authenticity.
- Authority.
- Integrity.
- Confidentiality.

Privacy

Privacy, and the protection of privacy, is more than a security issue. It should be noticed that only a few of the threats to privacy corresponds to the technological part of the e-Health system, while the rest depends on factors such as the degree of trust in the medical relationship between patient and doctor.

2.4.- Architecture

ETSI proposes a 3-layer architecture to solve certain interoperability problems. Figure 2.5 shows the recommendation [6]:

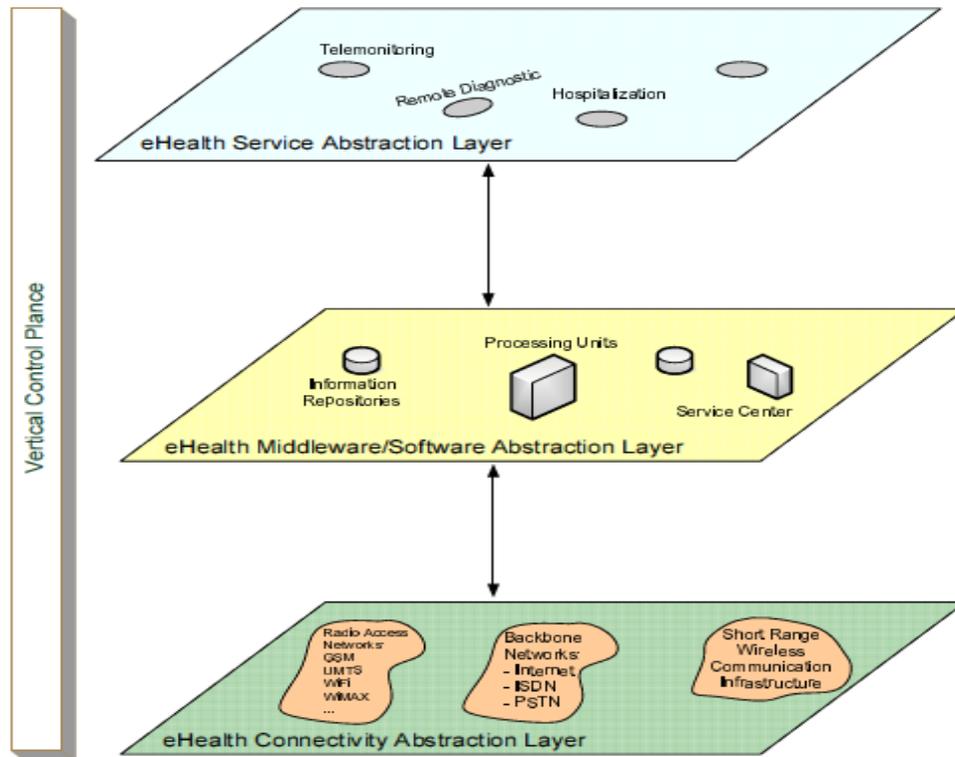


Figure 2.5: Top level e-Health architecture [6]

- e-Health service abstraction layer: e-Health user services are described in this layer. It also provides the combination of the data and functionality contained in the two lower layers.
- e-Health middleware abstraction layer: contains the necessary functionality to operate regardless of the ICT platform used to transfer data. Service-Oriented Architecture (SOA) will be a strong plus to make the services interoperable.
- e-Health connectivity abstraction layer: contains and defines the ICTs needed by the service to connect the devices and collect the data required for the e-Health system.

Each e-Health initiative is applied in different physical environments and interested in specific type of data. The idea is to obtain interoperability in the e-Health middleware layer so that ICTs can be used in the situations to which they were designed.

The interfaces between the layers must be such that changes in any of them don't disrupt the other in terms of performance.

This architecture will be used in next sections.

3.- m-Health

The growing coverage of mobile networks together with the fact that nearly 90% of the world is connected via cellular telephony (ITU statistics suggest that almost 6 billion people have mobile phone subscriptions) are some of the reasons why m-Health is so up-to-date. This coverage supplies health systems with new possibilities to improve the delivery of healthcare all over the world. But m-Health is much more.

3.1.- What is m-Health

m-Health stands for the provision of health-related services using mobile communication technologies, not only mobile phones. In other words, m-Health is wireless e-Health.

Wireless communications overcome some of the limitations of wired communications. First, the geography of the terrain can be a determining factor when deploying a wired solution such as in mountain zones. Second, the length of the wire required determines the system's cost so that the more wire used the more expensive the system. And last but not least, freed from the traditional constraint of wires, customers/patients will have a greater comfort.

In June 2011 the World Health Organization (WHO) global published a survey of m-Health developments in 114 nations [7]. The results of this work are shown in Figure 3.1

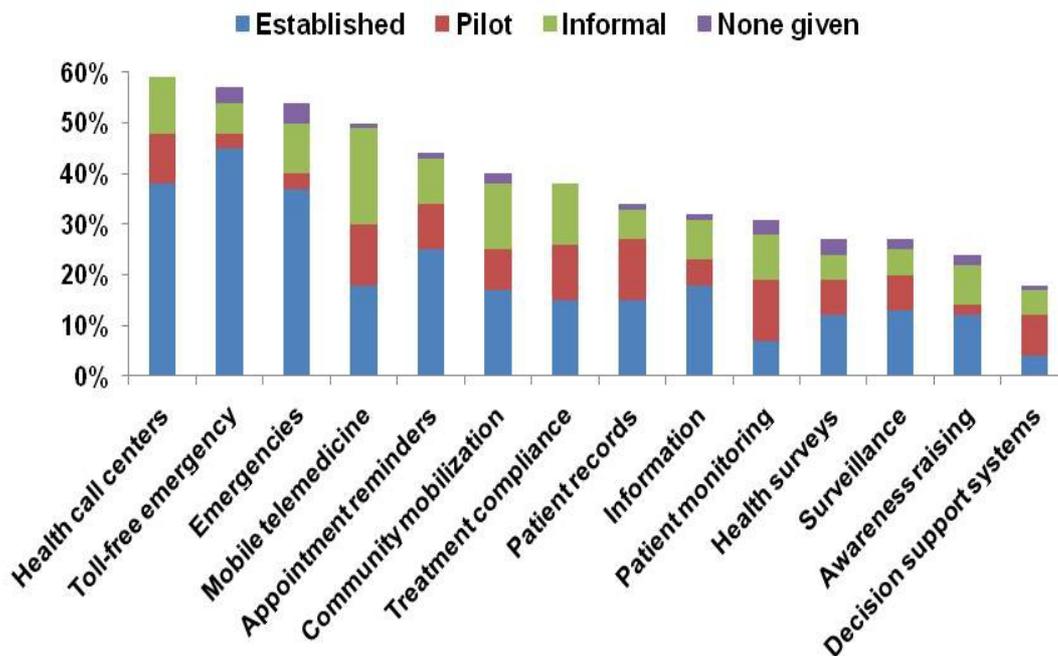


Figure 3.1: Adoption of m-Health initiatives and phases, globally [22]

The deployment of the various m-Health programs is at different stages depending on the country surveyed. For the purpose of the survey, these steps were reported as:

- Informal: programs used for health-related issues but not part of any official health initiative.
- Pilot: m-Health projects being tested and evaluated in a given situation are in this category.
- Established: official health plans based on the use of m-Health initiatives.

Among the m-Health categories defined, health monitoring and surveillance initiatives, which encompass patient monitoring (30%), health surveys (26%) and surveillance (26%), were almost the least reported. Also, interesting to notice is the fact that less than 10% of the countries asked have patient monitoring programs established.

The main result of the survey is that mHealth succeeds in voice services over traditional phone networks (e.g. Call centers (59%), emergency toll-free telephone services (55%), emergencies (54%) and mobile telemedicine (49%)) while applications requiring more advanced functionality and ICT (e.g. Patient monitoring) are not commonly established.

Another point to be highlighted is that most of the mHealth deployments tend to be small-scale pilots orientated to deal with single issues.

3.2.- Key features of m-Health

M-Health is not just a communication channel, it refers to the delivery, facilitation, and management of health-related information via mobile devices. The opportunities associated with its implementation may be very helpful for improving healthcare. However, there are still some barriers to their full deployment. These are the points to be discussed in this section.

3.2.1.- Mobile devices

Of all the ICTs employed in healthcare, mobile technologies have some special characteristics that make them more suitable to certain health-related activities [8]. Most mobile devices share the following features:

- They include wireless cellular communication capability (e.g. SMS, MMS and telephone calls) and access to the Internet.
- Their reduced dimensions and light weight as well as their rechargeable batteries make them portable.
- Nowadays, current models have sufficient computing capabilities to support multimedia software applications.

Mobile devices include cell phones, smartphones, PDAs and even tablets.

3.2.2.- Opportunities

In addition to the inherent benefits of e-Health, such as reduced cost and personalized and preventive care, m-Health is characterized by enhancing the quality and expanding the reach of health services [5].

On the one hand, m-Health enables real-time (or recent) care through remote continuous monitoring of any disease (especially important for chronic diseases) using wireless technologies which means that there is no need to visit care facilities so frequently.

On the other hand, m-Health is expected to enable pervasive access, allowing patients to continue with their lives whilst still in care and permitting clinicians to lighten the quantity of patients they have to deal with in the medical centre. In both cases, an improvement in quality of life and care is achieved.

Finally, m-Health will extend the reach of health services through the use of wireless communications. Diagnosis, treatment, monitoring and medical advice will be possible in remote or difficult to access places where qualified care may not be available. M-Health interventions will be of critical necessity for natural disasters and armed conflicts.

3.2.3.- Barriers

In the same survey [7] barriers to m-Health deployment in WHO member states were presented (See Figure 3.2)

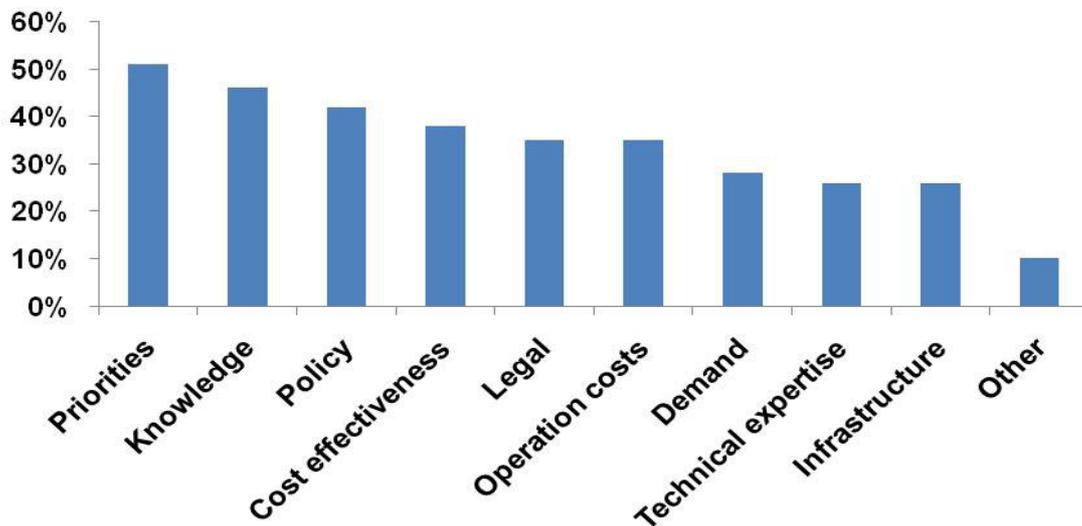


Figure 3.2: Barriers to m-Health implementation [23]

All the five parts of the m-Health ecosystem appeared as potential barriers to some extent. For example, the financing part is represented in cost-effectiveness and operation costs while policies and legal correspond to the governance part. Demand is related to the service part and technical expertise and infrastructure to technology. Stakeholders have interests in all of the issues treated in the survey.

A significant result from Figure 3.2 is that issues related to technology (e.g. Technical expertise and infrastructure) are not the most important barriers. In fact, infrastructure was cited as the least important barrier (26%). This means that mostly any m-Health initiative relies upon available and proven technologies.

The lack of a strong-evidence base on the feasibility of m-Health solutions makes most of the asked nations to prioritize initiatives based on expected return on investment (53%). The second most reported barrier corresponds to the little understanding in how m-Health can impact public health and its outcomes (47%).

Following these two top barriers, public policy, cost-effectiveness, legal issues and operational expenses to adopting mHealth programs. This fact highlights that the main barriers to m-Health implementation are not related to technology but close to governance and financial issues.

3.3.- New technical problems

When it comes to choosing one technology or another for a m-Health system, it is important to evaluate the frequency range in which they operate to ensure interoperability and the least amount of interference possible with other existing solutions in the environment. Also, given a concrete problem there is a tradeoff between standardized and proprietary solutions.

Not to forget, the unreliable nature of wireless channels due to constant fluctuations and noise. This problem may be aggravated indoors.

3.3.1.- Standardized and proprietary solutions

Standardized solutions promote interoperability between components from different manufacturers in a single system while this does not normally occur with proprietary ones. Thus the designer of a standardized m-Health scheme can choose such components according to various criteria such as economic, for example. However, proprietary systems permit a higher degree of customization being able to better suit new needs but usually at a higher cost.

3.3.2.- Interferences

Several wireless technologies, mainly those intended to operate in short ranges and with low power consumption, use frequencies allocated in the industrial, scientific and medical (ISM) radio bands which are reserved internationally for the use of radio frequency energy for industrial, scientific and medical purposes rather than for communications. Examples of applications in these bands include radio-frequency process heating or microwave ovens.

Nowadays, communication devices using the ISM bands must tolerate any interference from ISM equipment as well as from other communication systems in the same frequency band. For example, wireless technologies in the 2.4GHz ISM band are ZigBee, Bluetooth and some Wi-Fi versions which means a lot of possible interferences between different communication systems.

4.- Technologies supporting m-Health

M-Health aims to improve the quality of care and reduce healthcare costs. Some technologies especially suitable to serve to these purposes together with their possible network architectures and devices are describe here. In accordance with the architecture in 2.4, these technologies are encompassed in e-Health connectivity abstraction layer.

4.1.- M2M, Cloud computing and the Internet of Things

The gradual introduction of the IPv6 address space along with recent advances in the field of M2M and Cloud computing seem to approach us to the Internet of Things. These concepts are briefly described, showing the potential effects on m-Health.

4.1.1.- M2M

Machine to machine (M2M) is not a new issue and refers to technologies that allow both wireless and wired systems to communicate with other devices of the same ability. Such communications are meant to use equipment characterized by low power and cost, small size and able to operate with little human intervention for long periods of time [9]. These restrictions will be taken into account further on.

M2M operating consists of three phases [10]: data collection, data transmission, and data processing. In the first phase, an event of interest is captured by devices such as sensors or meters. Then, during the second one, this event is transmitted by a gateway through a network to an application, which translates it into meaningful information in the last stage. Figure 4.1 shows the different domains involved in M2M communications.

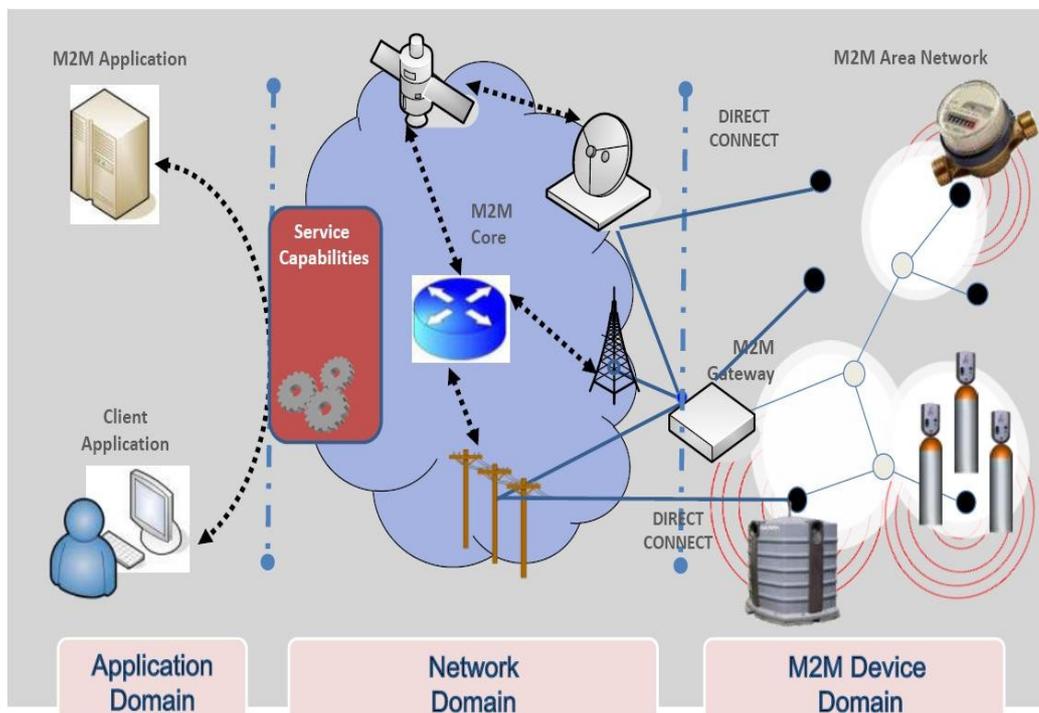


Figure 4.1: M2M basic domain architecture [11]

The general architecture of M2M networks is also divided into three layers or domains as the architecture discussed in 2.4. Not for nothing the two architectures have been proposed by ETSI and it is possible to see them as interoperable.

In reference to the architecture, M2M devices are deployed within an M2M area network, which will be based on short-range wireless technologies. This is called device domain and provides connectivity between the different M2M devices and the M2M gateway. In the same manner, the access network (network domain) that carries the data from the M2M gateways to the M2M applications will rely upon long-range wireless technologies [12]. This areas and technologies are properly detailed in the following section.

A recent use of M2M applications is in the field of remote healthcare monitoring. Typically, several sensors are used to capture some patient's vital signs which are then sent to a medical centre in regular intervals [11]. Of course, each illness will have its own treatment and the M2M application performance must be adapted to this situation. However, typical requirements for health on the network domain, among other M2M applications, are summarized in Figure 4.2

| | Smart meters | eHealth | ITS | Surveillance |
|-----------------|--------------|---------|--------|--------------|
| mobility | none | normal | high | none |
| message size | low | medium | medium | high |
| traffic pattern | regular | random | random | regular |
| device density | high | medium | high | low |
| latency req. | low | high | high | medium |
| power eff. | high | high | low | medium |

Figure 4.2: Requirements of different M2M uses cases on network domain [13]

4.1.2.- Cloud computing

The National Institute of Science and Technology (NIST) defines Cloud computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction”.

In other words, Cloud computing may allow the m-health system to manage the data collected by M2M devices to be accessed on-demand by physicians, patients and other medical actors from any place. Cloud computing is of utmost importance for the success of initiatives as EHR and for m-Health to provide a full solution to chronic diseases management as it will be appreciated further on. Also, related to Cloud computing and data management is the concept of Big Data which escapes the scope of this project.

Furthermore, today, modern M2M communication and Cloud computing together have improved communications between remote machines by lessening the necessary amount of power and time, and eliminating the manual process of collecting information.

4.1.3.- Internet of Things

Although the Internet of Things (IoT) has not a clear definition, it is commonly seen as the networked interconnection of any kind of devices, uniquely identifiable, using some internet protocol to communicate. The idea is to interconnect everyday objects (called “things”) through the internet, not only computers, smartphones and devices of the like but also household appliances and medical devices, for example.

Thus, IoT extends the current concept of the internet by enabling anything to be accessed anytime anywhere by any path. Figure 4.3 presents the benefits of IoT.



Figure 4.3: Benefits of the Internet of Things [24]

M2M and Cloud computing are two of the pillars of the IoT paradigm as shown in Figure 4.4:

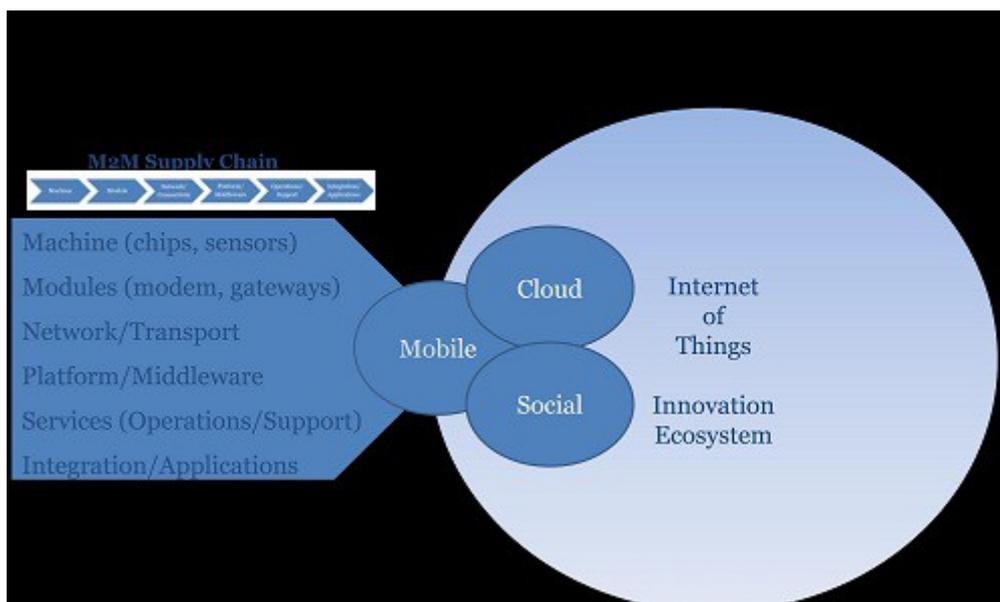


Figure 4.4: Relation between M2M, Cloud computing and IoT [25]

4.2.- Wireless networks

In this part, most commonly networks used in m-Health solutions, ranked from smallest to biggest area of influence, are briefly described (see Figure 4.5).



Figure 4.5: Network level for m-Health [14]

According to M2M domains, Body and Personal Area Networks will act as device domains while Local and Wide Area Networks will correspond to network domains.

Then main wireless technologies associated with these networks are discussed and compared. In Figure 4.6 some of them are presented.

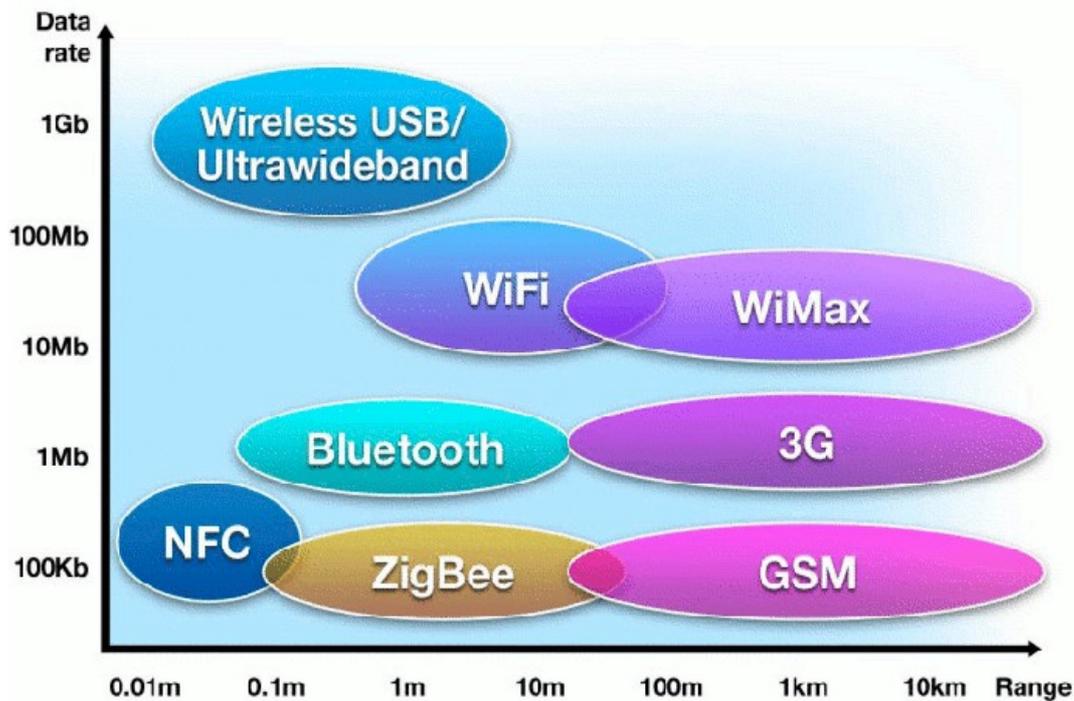


Figure 4.6: Data Rate vs Range for some wireless technologies [26]

4.2.1.- Wireless Body Area Network (WBAN)

As the name suggests the area of influence of a WBAN is centered in the vicinity of the human body and its reach is a few meters. For the purpose of this thesis a WBAN consists of a Wireless Sensor Network (WSN) and an access point or gateway. From the point of view of M2M communications it will be the most fundamental device domain.

Nowadays, there are two types of sensors used in such a WSN: wearable and implantable [15]. Sensors belonging to the first class, located within the vicinity of the body, are designed to provide health monitoring whilst the ones belonging to the second, although put into the tissues of the human body, usually have more functions like automatic drug delivery. For this reason, implantable sensors seem to be quite interesting an option to deal with chronic diseases.

Both kinds of sensor are desired to be small, lightweight and inexpensive. In this sense, wearable sensors are cheaper than implantable. They also require accurate sensing, a certain level of signal processing, as well as some wireless features, and long lifetime.

Two types of communications take place in the WBAN: intra-WBAN communications and inter-WBAN communications (See Figure 4.7).

- Intra-WBAN refers to the communications among the sensors/actuators deployed on the human body.
- Inter-WBAN refers to the communications between WSN and the gateway which connects the BAN with other BANs or other kind of network.

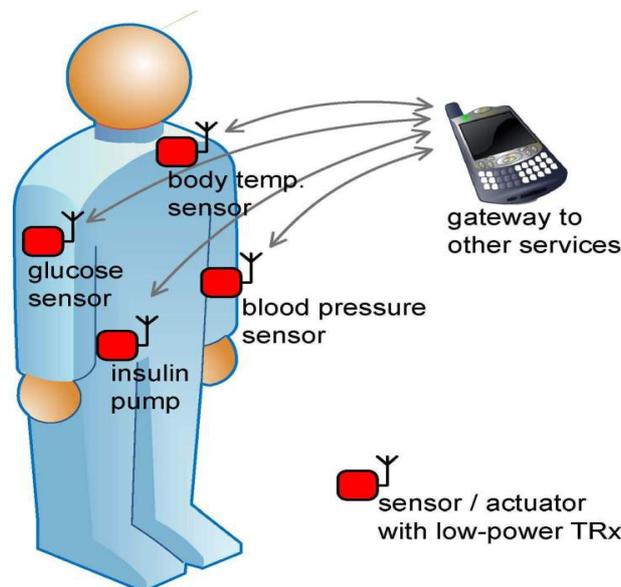


Figure 4.7: Example of a Body Area Network [27]

BAN wireless technologies

Short-range technologies appropriate to fit WBAN requirements are the following:

- Ultra-Wide Band (UWB) is a communication method used in wireless networking to achieve high bandwidth connections with low power utilization. UWB supports high wireless data rates of 480 Mbps up to 1.6 Gbps at distances up to a few meters. At longer distances, UWB data rates drop considerably which makes it suitable for WBAN and WPAN.
- Bluetooth is a wireless technology that allows devices to communicate, or transmit data or voice, wirelessly over a short distance. According to the Bluetooth SIG Bluetooth is "a short-range communications technology intended to replace the cables connecting portable and/or fixed devices while maintaining high levels of security.". Operating in 2.4GHz spectrum, Bluetooth was intended as a wireless replacement for cables. By creating a 10-meter radius wireless network, called piconet, which can network between 2 and 8 devices with data transfer below 1Mbps.
 - Bluetooth version 4.0 features include: low energy consumption, low cost, multi-vendor interoperability, and enhanced range.
- Zigbee is a standard that utilizes the 802.15.4 standard. It works on the 2.4GHz band, although some companies are exploring the design of 915MHz to resolve the range and interference issue faced in the 2.4GHz Zigbee products. Unlike IEEE 802.15.4, Zigbee allows full mesh network.

Table 1 shows a comparison of the most important characteristics for the sensors in WBAN:

| | ZigBee | Bluetooth LE | UWB |
|--------------|------------------------------|--------------|---------------------|
| Throughput | 250kb/s | 1Mb/s | 1 to 2 Gigapulses/s |
| Coverage | Up to 20m | Up to 15m | Up to 10m |
| Power | Low | Low | High |
| Battery life | Years | Years | Hours |
| Frequency | 2,4GHz, 868MHz, 915MHz | 2,4GHz | 3,1 to 10,6GHz |

Table 1: WBAN technologies

Our interest is in health WSN and here the need to replace or recharge batteries is undesirable for wearable sensors, and is totally unacceptable for any implantable ones. UWB fails to satisfy this requirement.

ZigBee and Bluetooth, both are compatible with M2M communications and the IoT paradigm.

4.2.2.- Wireless Personal Area Network (WPAN)

PAN technology allows communications among e-Health devices up to 10-20 metres, increasing slightly the scope of those in WBAN. However, the coverage of ZigBee and Bluetooth LE makes them suitable for operating in WPAN (See Table 1). Also protocols from 802.11 family fulfill the conditions to work in WPAN.

WPAN operation is very similar to WBAN as it is also decomposed into two types of communication intra and inter-PAN. The utility of WPAN may be in the integration of health WSN into other systems to provide Ambient Assisted Living (AAL) services within IoT for elderly people or patients suffering from chronic diseases, as the ones object of this project.

4.2.3.- Wireless Local Area Networks (WLAN)

Local area communications refer to communications between the subnetworks (e.g. WBAN and WPAN in this project) and the external network, or among machines in the home area. The information of this subsection is based on [16] and updated with the specifications in the WiFi Alliance website (www.wi-fi.org/).

LAN wireless technologies

Mainly, wireless technologies in LANs belong to the family of protocols IEEE 802.11. First standard only supported a maximum network bandwidth of 2 Mbps - too slow for most applications. Successive standards in order of appearance on the market are:

- 802.11b: uses the unregulated radio signaling frequency (2.4 GHz) and supports bandwidth up to 11 Mbps, comparable to traditional Ethernet.
- 802.11a: supports bandwidth up to 54 Mbps and signals in a regulated frequency spectrum around 5 GHz. This higher frequency shortens the range of 802.11a networks, and also means that 802.11a signals have more difficulty penetrating walls and other obstructions.

Because 802.11a and 802.11b utilize different frequencies, the two technologies are incompatible with each other. Due to its higher cost, 802.11a is usually found on business networks whereas 802.11b better serves the home market.

- 802.11g: attempts to combine the best of both previous standards as it supports bandwidth up to 54 Mbps, and it uses the 2.4 GHz frequency for greater range. Moreover, 802.11g is backwards compatible with 802.11b, meaning that 802.11g access points will work with 802.11b wireless network adapters and vice versa.
- 802.11n: was designed to improve on 802.11g in the amount of bandwidth supported by utilizing multiple wireless signals and antennas (called MIMO technology) instead of one. 802.11n connections may support data rates of over 100 Mbps and a better range over earlier Wi-Fi standards due to its increased signal intensity. Its equipment will be backward compatible with 802.11g gear.

In Table 2, a comparison between the standards of 802.11 family is summarized:

| | WiFi (a) | WiFi (b) | WiFi (g) | WiFi (n) |
|-------------------|------------------------------|----------------------------------|------------------------------------|---|
| Standard | 802.11a | 802.11b | 802.11g | 802.11n |
| Frequency (GHz) | 5 | 2,4 | 2,4 | 2,4 / 5 |
| Throughput (Mbps) | Up to 54 | 11 | Up to 54 | >100 |
| Coverage | 50m | 100m | 100m | 70m |
| Advantages | Fast max. Speed Frequency | Low cost, coverage | Speed, not easily obstructed | Fastest speed, robust against interferences, compatible with WiFi (g) |
| Disadvantages | Cost and coverage | Slow max. Speed Interferences | Interferences | Cost, interferences |
| Mobility | No | No | No | No |

Table 2: Comparison of 802.11 technologies.

All of them meet the requirements of M2M network domain for health purposes, although their features differ considerably. Nevertheless, the solution proposed further on will be such that it will not depend on a specific WLAN technology but it will be supported by the patient's one.

4.2.4.- Wireless Wide Area Networks (WWAN)

A Wide Area Network (WAN) is a telecommunications network that covers a broad area, in the range of several kilometers. That is, it may contain some of the previous area networks discussed. There is a lot of discussion about the end of Metropolitan Area Network (MAN) scope and the beginning of WAN one. For that reason and to simplify the issue, it is not considered the difference between MAN and WAN.

WAN wireless technologies

In this section we briefly describe the main wireless technologies that are used in WWAN, namely GSM (2G), UMTS (3G), LTE and WiMAX. The sources of this subsection are [16] and 3GPPP website (<http://www.3gpp.org/>).

- GSM (2G), which operates mainly in the 900 MHz or 1 800 MHz bands, is the most popular standard for mobile phones in the world, nowadays. Initially designed for voice communication (circuit switched), it provides slow data transfer speeds (up to 9.6 kbps). The latest evolution of GSM, GSM/EDGE Evolution (2.75G) permits 1.3 Mbps in the downlink and 653 kbps in the uplink.
- UMTS (3G) is based on the GSM standard, although it requires new base stations and new frequency allocation (5MHz). However, since UMTS handsets are generally dual-mode to support GSM, roaming between the two networks is typically transparent. High-Speed Packet Access (HSPA) refers to the various software upgrades to achieve higher speeds.
 - High-Speed Downlink Packet Access (HSDPA) increases download data rates to top 14.4 Mbps, with most operators offering speeds up to 3.6 Mbps. Upload speeds are 384 kbps.
 - High-Speed Uplink Packet Access (HSUPA) increases upload rates to a maximum of 5.7 Mbps.
 - HSPA+ enables speeds up to 42 Mbps in the downlink and 11 Mbps in the uplink.
- LTE is a standard for high-speed data wireless communication for mobile phones, based on the GSM/EDGE and UMTS/HSPA network technologies and designed to support roaming Internet access via cell phones. LTE can theoretically support downloads at 300 Mbps and uploads at 17 Mbps. However, LTE service is only available in limited geographic areas, but telecommunications providers have been actively expanding their LTE services.
- WiMAX is a standard for long-range wireless networking which can function over a distance of several kilometers with data rates reaching up to 75 Mbps, using the frequency range between 2 GHz to 66 Ghz. Its much higher cost makes WiMAX not a replacement for Wi-Fi home networking or Wi-Fi hotspot technologies.

Some refer to LTE and WiMAX as 4G technologies because of the significant improvements over older cellular communication standards in terms of speed and range but they don't fulfill all the conditions to be truly called 4G.

Typically, cellular networks cover over 90% of a country while the coverage of WiMAX is usually less extensive.

Table 3 contains the key aspects of these standards, in their latest update:

| | GSM-EDGE Evolution | UMTS-HSPA+ | LTE | WiMAX |
|----------------|--------------------|-----------------------|-----------------------|----------------|
| Speed downlink | 1.3 Mbps | 42 Mbps | Up to 300 Mbps | Up to 75 Mbps |
| Speed uplink | 653 Kbps | 11 Mbps | Up to 170 Mbps | |
| Content | Voice | Voice, data and video | Voice, data and video | Data and video |
| Mobility | Yes | Yes | Yes | Yes |

Table 3: WWAN communication technologies

4.3.- Smartphones

To date, the most-widely used mobile device capable of supporting the exposed technologies and also act as both linker or gateway between between the various possible ICTs involved in the m-Health system is the smartphone. In other words, the smartphone can act as e-Health middleware abstraction layer in 2.4. It also can store some of the upper layer services.

In addition to that, IDC estimates that during 2013 the manufacturers of smartphones will dispatch 918.6 million, equivalent to 50.1% of total industry shipments. By 2017, the number of smartphones shipped will be 1,500 million, representing two thirds of the total mobile market (see Figure 4.8).

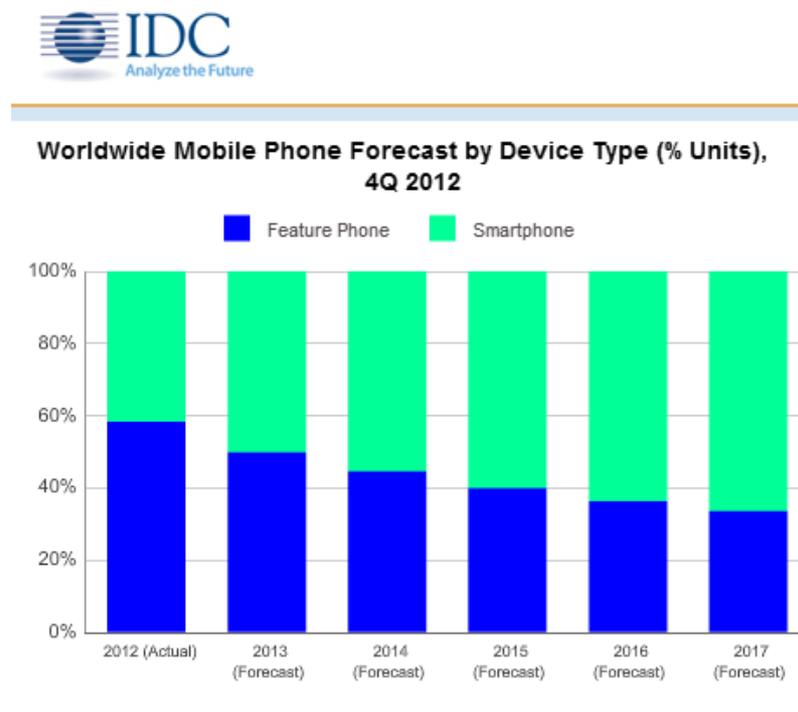


Figure 4.8: Mobile phone forecast [28]

4.3.1.- Mobile Applications

A mobile application (or mobile app) is a software application designed to run on smartphones, tablet computers and other mobile devices such as PDAs. There are two general types of mobile apps:

- Native apps can be downloaded from the market place associated with the operating system and executed on a mobile device.
- Nonnative apps are web-based apps, that is, they are executed on a server. This apps don't need to be install in the mobile device but they are accessed through the appropriate web browser or other interface enabled.

According to the FDA's Draft Guidance for Industry and Food and Drug Administration Staff: Mobile Medical Applications, a “mobile medical app” for a mobile device is a mobile app that transforms this mobile device into a regulated medical device.

When choosing a medical application for a specific disease, the usability of the application, which is defined as its ease of use and learning, plays a major role in the user's decision. The usability of an application can be measured by checking the following attributes, for instance [17]:

- Efficacy
- Efficiency
- Simplicity
- Naturalness
- Consistency
- Feedback

4.3.2.- Accessories

The proliferation of medical accessories for smartphones seems to be trend at present. This kind of accessories permits the users to convert their smartphones in portable medical devices. Peripherals such as blood glucometers or blood pressure monitors are available in the market.

4.3.3.- Limitations

Nonetheless, smartphones have constraints on the impact of its performance as a medical device, namely, limited memory and screen size.

Even though each new smartphone model released increases the usable memory, some medical applications may need more. In regard to this limitation, the mobile terminal may behave as a thin client and store only part of the application, which is hosted in a server. Cloud computing, discussed in 4.1.2, may help to overcome this issue.

The same thing applies to the screen size. The fashion is to develop bigger screens with new releases but they may not be enough to assure an adequate performance of the application. Designing applications so as to make them portable between the smartphone and the computer, for example, could be the solution to this problem.

4.4.- General remarks on technologies

In this section, two of the layers proposed in the architecture in 2.4 have been discussed. The most remarkable points of each technology presented have been highlighted and commented. Those are not the only technologies capable of facing the challenges proposed by m-health services but the most representative. Neither is the chosen gateway linking both layers, although it is the most widespread.

5.- Communications architecture

In this section we show the most common topologies used in wireless networks, including a discussion about their advantages and disadvantages. Next we describe and compare two structures of information commutation: server-client and peer-to-peer (P2P) paradigms.

5.1.- Topologies

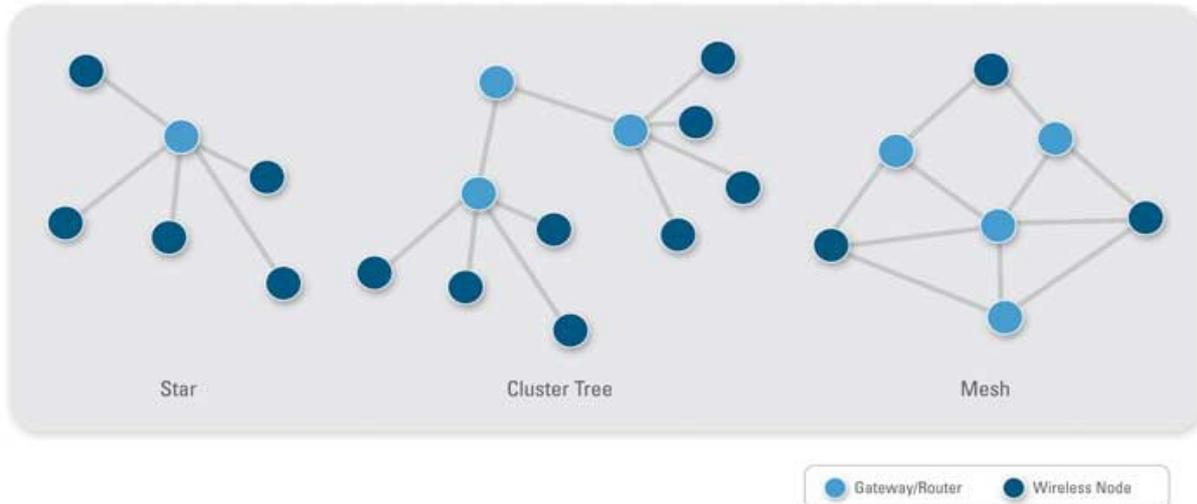


Figure 5.1: Network topologies [29]

5.1.1.- Star topology

This topology consists of a coordinator and several end devices or nodes. The communications permitted are always between a node and the coordinator that is any packet exchange between end devices must go through the coordinator.

The disadvantage of this topology is that in certain situations the coordinator may become bottlenecked. Consequently, as there is only one path from the source to the destination and it's through the coordinator, if it fails so does the network.

The main advantage of star topology is that it is simple. But it's not the only one. Star topology allows easy connection and removal of new nodes or devices as well as centralized management. Finally, failure of one node or link doesn't affect the performance of the system.

5.1.2.- Tree topology

In this topology, the network consists of a central node called root tree, which coordinates the network, several routers or gateways, and end devices. The function of the gateway is to extend the network coverage. The end nodes that are connected to the coordinator or the routers/gateways are called children. Only gateways and the root tree (parents) can have children. Each end device is only able to communicate with its parent (router or coordinator).

There are several drawbacks with this topology. First of them, if one of the parents becomes disabled, its children become isolated. Second, even if two nodes are geographically close to each other, there is no direct communication between them. Last, the more nodes the most difficult to maintain the system.

However, tree topology presents some advantages such as easy expansion of the network and error detection and correction.

5.1.3.- Cluster tree topology

A cluster tree topology is a special case of tree topology in which a parent with its children is called a cluster, which is uniquely identified by a cluster ID.

5.1.4.- Mesh topology

This is a multihop network in which packets pass through multiple hops to reach their destination. The main characteristic of this topology is that any source device can communicate with any destination device in the network.

Nevertheless, there are high chances of redundancy in many of the network connections. Not only does the overall expense exceed the cost of the other topologies but also its set-up and maintenance, even its administration, are difficult issues.

Among the advantages there is its ability to withstand heavy traffic as data can be transmitted from different devices simultaneously. Even if one of the components fails there is always an alternative path. Also, expansion and modification in the topology can easily be done without affecting the performance of the rest of the network. Lastly, distances between devices can be as short as desired so less power is needed for a communication.

5.2.- Paradigms of communication

The two most common structures of information commutation among electronic devices are described here.

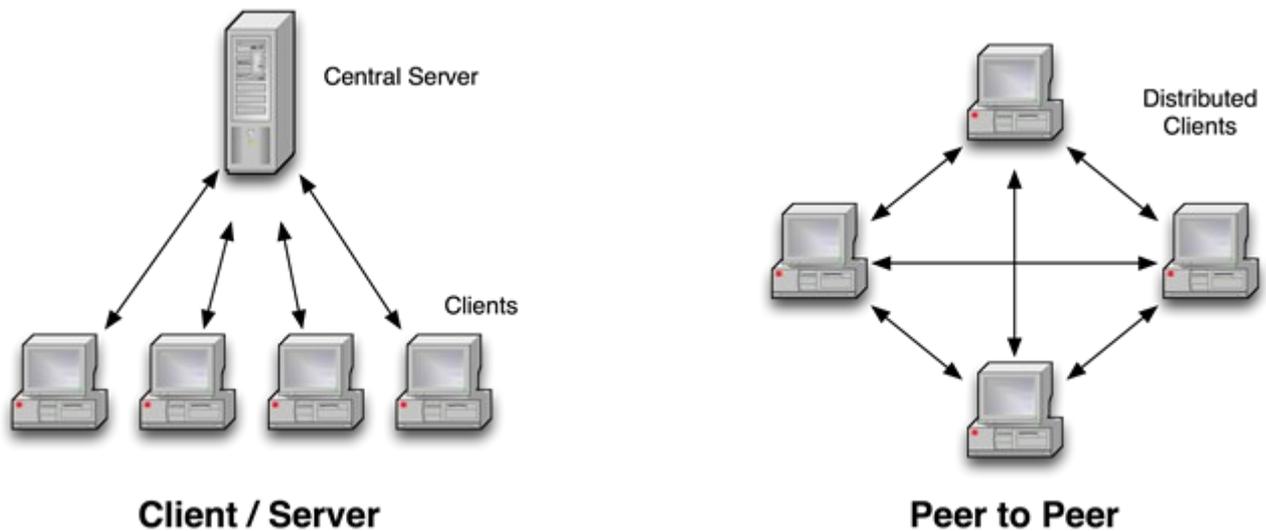


Figure 5.2: Structures of information commutation [30]

5.2.1.- Client-Server architecture

This model allows the devices in the network to act either as client or as server. The latter is the device that has the resources to be shared in the network and the former is the one that ask for and makes use of them.

The advantages and disadvantages of this architecture reside in the device which acts as a server. It simplifies enormously the management of the network but at the same time its capabilities determine network ones and it could also be a bottleneck.

5.2.2.- Peer-to-peer architecture

In a P2P network each device can act as a client or a server for the rest of the devices within this network, allowing shared access to various resources such as sensors without a central server.

P2P is a distributed architecture that partitions tasks or workloads among peers which are all equal. This means that no node is indispensable for the correct functioning of the network. Each node in the network will share its resources in order to make them directly available to any other node, without the need for central coordination.

With this model, the scope of the network is virtually infinite as it depends on the number of nodes connected which are both suppliers and consumers of resources.

5.3.- General remarks of the architecture

The choice of the topology of the network and communication paradigm depends on the m-Health application but typically it will be a combination of more than one of them. The idea behind this trend is based on the need to meet the different requirements in the ICT layer that may be defined by the m-Health service.

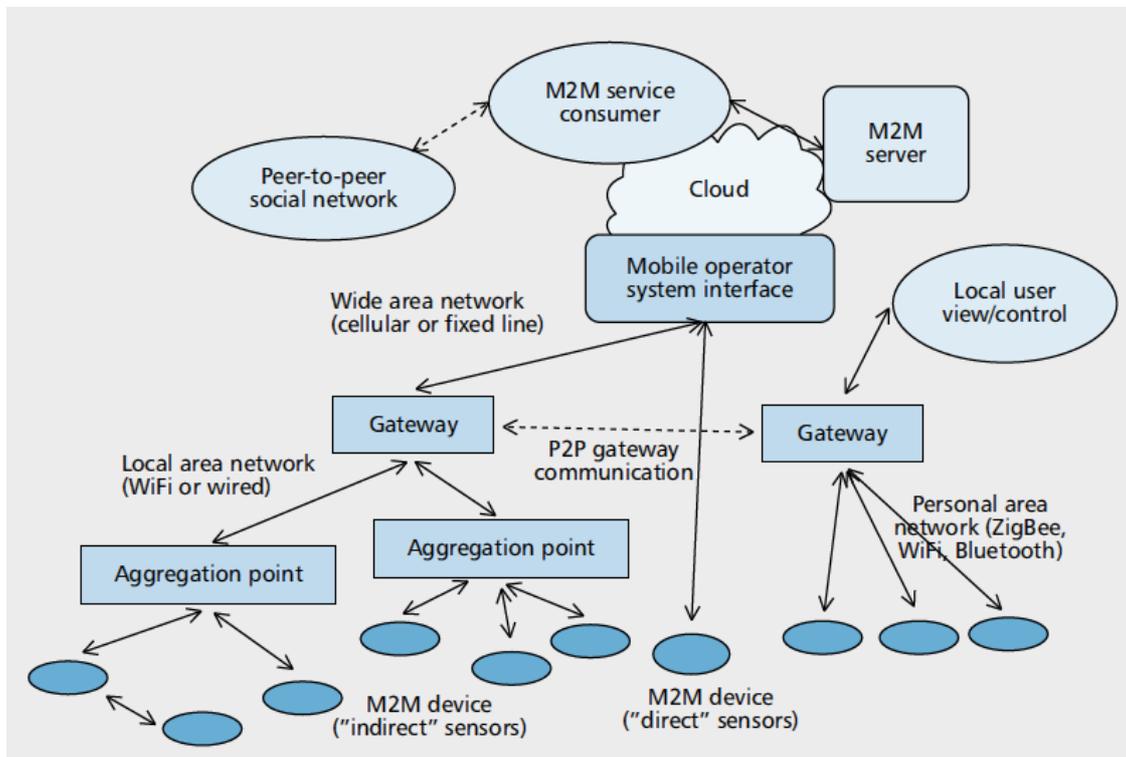


Figure 5.3: Possibilities of M2M communications [18]

For instance, inside a WSN a combination of mesh topology and P2P model could be interesting for intra-communications between sensors while data transmission from the gateway to the back end structure may be done with a Client-Server model and a star topology. However, the technology used in the solutions may also limit these possibilities.

6.- Chronic diseases

The World Health Organization (WHO) defines chronic diseases as “diseases of long duration and generally slow progression, such as heart disease, stroke, cancer, chronic respiratory diseases and diabetes”.

6.1.- Special needs for chronic diseases

Common to every chronic diseases is the need of an adequate diagnosis and continuous monitoring to both keep record of the evolution of the disease and the success of the treatment trough time. Also, patients need to be aware that their lifestyle influences the progress of the disease. These special needs lead to a new care model for chronic diseases based on personalization and patient self-management by continuous and remote monitoring [15].

6.2.- Characteristic medical stages and requirements

It is the purpose of this subsection to state the characteristic stages of chronic diseases and their requirements from a medical point of view [19].

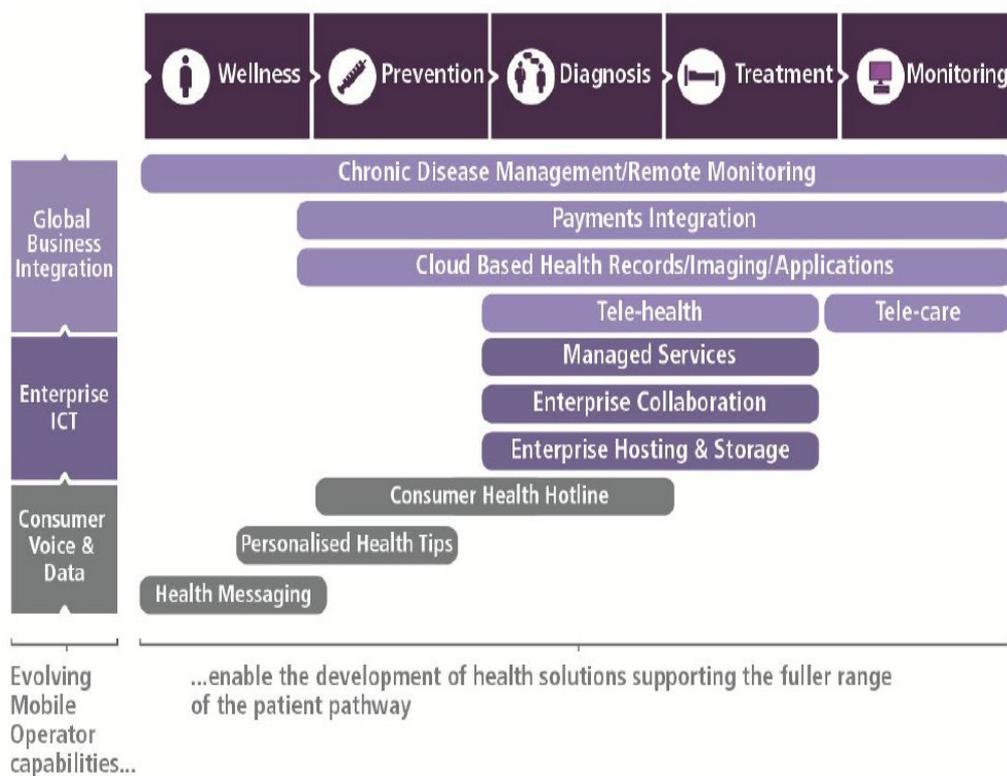


Figure 6.1: Relation between ICT development and medical services supported [31]

6.2.1.- Wellness

WHO defined health in its broader sense in 1946 as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." In other words, wellness is part of the goal of health care, which is not only cure but to make bearable the disease while it lasts, or, if chronic, to provide necessary relief and moral support.

6.2.2.- Prevention

Prevention refers to the set of measures, pharmacological, hygienic, surgical or any other type, to avoid the onset of diseases. Preventive medicine is the branch of medical science dealing with these methods.

6.2.3.- Diagnosis

Medical diagnosis (often simply termed diagnosis) refers both to the medical judgment about the nature of the illness or injury of a patient based on the assessment of signs and symptoms, and also to the selection between these diseases. From the point of view of statistics the diagnostic procedure involves classification tests and it is a major component of, for example, the procedure of a doctor's visit.

6.2.4.- Treatment

Treatment or therapy involves the application of technical measures aimed at the recovery of health, usually following a diagnosis.

6.2.5.- Monitoring

In medicine, monitoring is the control performed through a display, where one can observe the information received from sensors connected to a patient over time. It can be performed by continuously measuring certain parameters by using a medical monitor (for example, by continuously measuring vital signs by a bedside monitor), and/or by repeatedly performing medical tests (such as blood glucose monitoring with a glucose meter in people with diabetes mellitus).

7.- Managing chronic diseases through remote healthcare

Managing chronic diseases through remote monitoring and mobile devices is one of the purposes of m-Health but not the only. M-health also permits remote clinical care and diagnostics, and mobile access to health information for a full solution to a specific disease [20], as indicated in Figure 7.1:

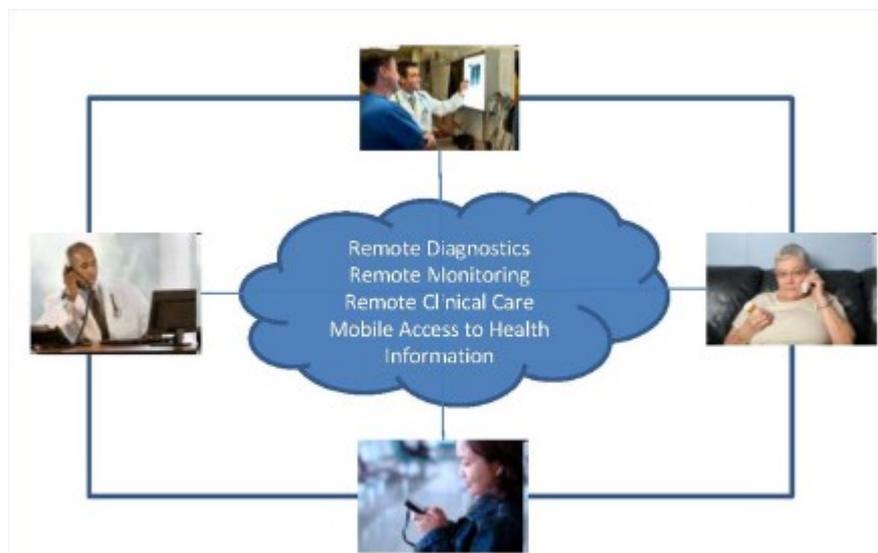


Figure 7.1: Parts of remote healthcare supported by m-Health [20]

The pervasiveness of wireless ICTs and the relatively low cost of devices led to a great progress in developing these initiatives.

7.1.- Remote patient monitoring

Remote patient monitoring (RPM) is a practice where the patients are monitored remotely by using a set of sensors and devices (e.g., at home). The recordings of these devices are transmitted to the health care provider via some ICT infrastructure.

Thus, patients with chronic diseases are enabled to record their own health measures and send them electronically to the appropriate specialists when required or agreed. Current technologies support real-time management which could be especially important for acute episodes and allow the incorporation of such remote monitoring devices into smartphones or tablets both as hardware (special models) and as software (apps). And given the growing expansion of this kind of devices, it is an opportunity hard to obviate.

In the case of a diabetic the control of multiple parameters is required: blood pressure, weight, and blood glucose. The real-time delivery of blood glucose and blood pressure readings enables immediate alerts for patient and healthcare providers to intervene when needed.

7.1.1.- Mobile patient monitoring

Mobile patient monitoring (MPM) is part of and extends the reach of RPM by allowing patients to receive care while being away from home. MPM uses portable wireless devices to provide such services, mainly mobile phones or smartphones in developing and developed countries, respectively.

7.1.2.- Limitations

RPM is still a costly practice and it needs extensive wireless ICTs so it is not widely spread yet. In fact, RPM would suppose a profound renewal of the medical equipment. Furthermore, depending on the chronic disease monitored, different comorbidities² may appear implying a diverse selection of devices in the implementation for each patient.

Moreover, the success of such initiative is highly dependent on the patient's motivation to be active in the management of their health. Caregivers will also need to learn how to use RPM.

The continuous flow of patient data requires a dedicated team of health care providers to handle the information, which may, in fact, increase the workload and involve the use of Big Data solutions. Also, tandardization is required for data exchange and interoperability among multiple components.

Finally, since RPM involves transmission of sensitive patient data across telecommunication networks, information security is a concern.

7.2.- Remote access to medical information

All the data collected via remote or mobile monitoring may be aggregated to EHR and be accessible to patients and doctors allowing them to check periodically medical histories, for example.

7.3.- Remote clinical care and diagnostics

Caregivers will be enabled to diagnose, treat and give assessments remotely by evaluating patients' condition through the inspection of their EHR and the using of the wireless ICTs needed for the concrete disease under monitoring.

² In medicine, comorbidity is either the presence of one or more disorders (or diseases) in addition to a primary disease or disorder, or the effect of such additional disorders or diseases.

8.- Case of study: Diabetes

According to WHO definition, diabetes is a chronic disease that occurs either when the pancreas does not produce enough insulin or when the body cannot effectively use the insulin it produces.

In 2004, an estimated 3.4 million people died from consequences of high blood sugar, most of these deaths (over 80%) did and do occur in developing countries and WHO projects that there will be an increase of two thirds between 2008 and 2030.

Over time, diabetes can seriously damage the heart, blood vessels, eyes, kidneys, and nerves if not treated adequately. Here there is a list with some of the comorbidities associated with diabetes as referred in WHO website:

- Diabetes increases the risk of heart disease and stroke. 50% of people with diabetes die of cardiovascular disease (primarily heart disease and stroke).
- Combined with reduced blood flow, neuropathy in the feet increases the chance of foot ulcers and eventual limb amputation.
- Diabetic retinopathy is an important cause of blindness, and occurs as a result of long-term accumulated damage to the small blood vessels in the retina. After 15 years of diabetes, approximately 2% of people become blind, and about 10% develop severe visual impairment.
- Diabetes is among the leading causes of kidney failure. 10-20% of people with diabetes die of kidney failure.
- Diabetic neuropathy is damage to the nerves as a result of diabetes, and affects up to 50% of people with diabetes. Although many different problems can occur as a result of diabetic neuropathy, common symptoms are tingling, pain, numbness, or weakness in the feet and hands.
- The overall risk of dying among people with diabetes is at least double the risk of their peers without diabetes.

Diabetes treatment is based on blood glucose and pressure control, and foot care. In some situations, more procedures may be followed like screening and treatment for retinopathy (which causes blindness), blood lipid control (to regulate cholesterol levels) or screening for early signs of diabetes-related kidney disease. These measures should be supported by a healthy diet, regular physical activity, maintaining a normal body weight and avoiding tobacco use.

The two types of diabetes are briefly described next.

8.1.- Type 1 diabetes

Type 1 diabetes is characterized by deficient insulin production and requires daily administration of insulin. Symptoms include excessive excretion of urine (polyuria), thirst (polydipsia), constant hunger, weight loss, vision changes and fatigue. These symptoms may occur suddenly.

Nowadays, it is estimated that nearly 347 million people worldwide have diabetes ¹. The cause of type 1 diabetes is not known and it is not preventable with current knowledge.

People with type 1 diabetes require insulin treatments.

8.2.- Type 2 diabetes

Type 2 diabetes results from the body's ineffective use of insulin and comprises 90% of people with diabetes around the world, and is largely the result of excess body weight and physical inactivity. Symptoms may be similar to those of Type 1 diabetes, but are often less marked. As a result, the disease may be diagnosed several years after onset, once complications have already arisen.

Healthy diet, regular physical activity, maintaining a normal body weight and avoiding tobacco use can prevent or delay the onset of type 2 diabetes.

People with type 2 diabetes can be treated with oral medication, but may also require insulin.

8.3.- Medical devices and apparatus

Diabetes treatment relies upon blood glucose and pressure control, and insulin delivery devices, principally. Most common devices developed to deal with these issues are shown according to [15] and a diabetes-related website (www.diabetes.co.uk/) .

8.3.1.- Glucose control devices

Blood glucose is typically measured in a drop of capillary blood using a disposable needle and reader device, an uncomfortable and slow process. This process is usually performed by blood glucose meters several times a day. However, not long ago another type of glucose control device, characterized by measuring glucose in interstitial fluid, have also been developed.

- **Blood Glucose Meter**

A glucometer is a device for determining the approximate concentration of glucose in the blood and it is a key element of remote self-monitoring for people with diabetes.



Figure 8.1: Wireless blood glucose meter [32]

The principle used to determine the concentration of glucose in a sample of blood is based on the measuring the conductivity of the blood as is directly affected by the quantity of glucose present.

- **Continuous Glucose Monitoring**

Continuous Glucose Monitoring (CGM) uses sensors placed into body but not into the bloodstream, which measure the glucose in your interstitial fluid - the fluid in and around your body's cells. The relationship between glucose concentrations in interstitial fluid (ISF) and blood has generated great interest due to the possibility of gaining up to 288 glucose level readings a day without having to do finger pricks.

CGM consists of a glucose sensor, a transmitter, and a small external monitor usually built-in to an insulin pump to monitor glucose levels and act accordingly if these levels are anomalous, as shown in Figure 8.2.



Figure 8.2: Continuous glucose monitoring [33]

CGM monitor will show current glucose levels and historical glucose trends. It may also report before reaching high or low glucose limits and if glucose levels vary rapidly.

The glucose sensor, inserted under the skin to check glucose levels in ISF, usually in the abdomen, is meant to work for a few days and then replacement by a new sensor is needed.

CGM transmitter is attached to the glucose sensor, captures glucose data, and sends it wirelessly to the glucose monitor unit.

However, the regular use of fingerstick blood glucose readings it is highly recommended as a complementary measure in order to maintain the CGM calibrated for optimal glucose sensor accuracy.

- **Comparison**

In Table 4, strong points of both glucose control devices are highlighted:

| CGM | Blood glucometer |
|--|---|
| Less invasive | Faster as the level of glucose in interstitial fluid reacts slower than the level of glucose in the blood |
| Monitors 24/7 and may include alarms to report high or low levels of glucose | |
| Compatible with pump and needles | Cheaper |

Table 4: Comparison of glucose control devices

8.3.2.- Insulin delivery devices

There are many different types of insulin delivery devices available. Most common methods for insulin delivery are detailed below.

- **Syringe**

It is the most common and simplest device used for direct subcutaneous insulin injection. The capacity of the syringe must be chosen depending on the dose of insulin required. Other important factors are the caliber and length of the needle, both of which must be adjusted for comfort under the guidance of physician.

- **Insulin pen**

An insulin pen is an injection device that includes a needle and holds a vial of insulin. Insulin pens are either disposable one-shot devices prefilled with insulin or durable with replaceable insulin cartridges. They are also a discreet way to transport insulin, allowing insulin administration on the move.

- **Insulin pump**

These devices, which are worn outside of the patient's body, can be programmed to deliver a steady supply of insulin throughout the day. There are two kinds of insulin pumps: implantable and external.

- Implantable insulin pumps are implanted surgically, and can deliver insulin when required. They are still in development.
- External insulin pumps remain hard to access and expensive, many people with diabetes find them to be accurate, precise and flexible as insulin delivery systems providing tight blood glucose control.

Insulin pump therapy provides more flexibility for patient's lifestyle while giving greater control of diabetes by not having to follow a strict schedule for eating, activity, and insulin injections. Finally, insulin pumps are normally part of the CGM system.

Furthermore, insulin that can be inhaled and other new approached to insulin treatment are at different stages of availability and development all over the world nowadays.

8.3.3.- Blood pressure monitors

Blood pressure monitors, also called sphygmomanometers, are instruments for measuring blood pressure and especially arterial blood pressure. Figure 8.3 exhibits a typical wireless blood pressure monitor.



Figure 8.3: Blood pressure monitor [34]

Blood pressure monitors also record the information continuously. This feature makes them appropriate when the disease requires frequent monitoring.

There are two main kinds of blood pressure monitors depending on the place of measuring, namely: upper arm and wrist blood pressure monitors.

9.- Proposed system

The knowledge acquired in the previous sections will be used to design a functional patient-centric solution based on mobile technology opportunities within the e-Health needs for component parts and system integration and access in the case of diabetes. The architectures in 2.4 and 4.1.1 will serve as models for such a purpose.

9.1.- General considerations

The system is intended to manage diabetes through remote healthcare, that is, it will provide remote access to medical information, monitoring, clinical care and diagnostics by using mobile devices. Also the perspective of patients will be taken into account in order to facilitate the management of their disease in the best conditions.

The scheme discussed will be decomposed into two separate environments, namely: indoors and outdoors. The former refers to the part of the system to be deployed at home, which is the part designable, while the latter is a non-designable environment as the system will have to adapt to the technology available at each location. Each of them, anyway, presents particular characteristics to be overcome.

The design of the system will pay particular attention to the sensor network around patient's body and its operation along with the smartphone, which will act as the key element. Finally, the proposed solution will try to satisfy the requirements imposed by both types of diabetes.

9.2.- Patient's suggestions

A recent study on the preferences of diabetes-related users in Europe identifies advanced technology services for diabetes management by end users [15]. Next, these preferences are presented along with some remarks of interest:

Autonomy and self-management

Patients view technology as a tool that favours patient's autonomy in the management of their condition as well as prevents long-term risks.

Privacy and confidentiality

Diabetics consulted consider the privacy, confidentiality and performance of the communication system issues of most importance. The loss of and the unauthorized access to personal data were among their major concerns.

Diabetic person–care provider relationship

A close patient-doctor relationship is expected to report benefits to diabetes management by enabling accurate and fast assessments, diagnosis and responses to crisis, according to the results of the survey.

Health management

Participants think that the quantity of data required, the periodicity and the ease of use of the necessary services to manage diabetes will determine the success of the initiative.

9.3.- Smartphone requirements

Not only the smartphone will be the key component of the system, as discussed in 4.3, but it may also satisfy some of the suggestions in 9.2 as will be shown.

On the one hand, the smartphone provides autonomy and self-management due to its size and weight, and its computing capabilities, respectively. In addition to that, it is always carried on which may help to establish closer diabetic-doctor relationships.

On the other hand, both medical applications and accessories can be used in the smartphone, converting it in a medical device. The transformation of the smartphone into a diabetes-related device will be made through the combination of specific applications and accessories.

Last but no least, will act as the gateway between the various networks within the diabetes management system and as a coordinator within the WSN deployed around patient's body.

9.3.1.- Medical applications

The application or, typically, set of applications required to manage diabetes must include at least exercise, diet and monitoring functionalities as described in 8. Here are some remarks on them:

- Exercise app: it is meant to encourage the patient to the continuous practice of sports with the purpose of maintaining a normal body weight.
- Diet app: it serves to the same aim as exercise app but in this case by recommending a healthy diet.
- Monitoring app: it is probably the most decisive of the three. It will process and translate the raw data sent by the various sensors measuring certain vital signs of interest, often without patient intervention, which means M2M communication functionality as well. It will also warn both the patient and the doctor in case of anomalous glucose levels, and record these levels over time, probably in the Cloud to be accessible by authorized people as the own patient, the doctor in charge or some selected relatives, for example.

Moreover, these applications should be easy to use for the diabetics to play an active role in their self-management. That is, usability is of great importance in the selection of apps. Even, they should allow feedback for the doctors to diagnose or treat at a distance if necessary.

The customization of the application will enable the adaptation of the service to any circumstance and condition, and to the possible changes in the state of the disease.

Finally, it would be desirable for such apps to allow portability from the smartphone to the computer in order to counteract memory and screen size limitations. Also, it will serve as a back-up copy in case of smartphone loss or damage.

9.3.2.- Accessories

Accessories such as blood glucometers and blood pressure monitors can be plugged into the smartphone in order to collect the data related to glucose level or blood pressure. This will allow a more versatile management.

9.4.- Medical devices

Diabetes management is based on three medical devices: glucose meters, blood pressure monitors and insulin delivery devices. Their medical descriptions and characteristics have been discussed in 8.3. The election of one device or the other will depend on the patient and the doctor's advice.

However, it is important to distinguish between the medical devices that compose the WSN or WBAN and those that do not, because the requirements of each of them may differ greatly. Those within the WSN can also be categorized into sensors and sensor/actuators and must overcome some design challenges, mainly:

- Sensor size and weight impact directly patient's level of comfort and, thus, affect their wellness. As a recommendation, the smaller the sensor the better.
- Duration is another pivotal characteristic of sensors as they are supposed to operate during long periods of time.
- Sensing and wireless transmission reliability are also imperative for the nodes in the WSN.
- Sensors need to be secured to protect data from unauthorized access.
- Intelligence included in the sensor will provide some level of signal processing in the back end of the system.

The nodes included in the WSN must be compatible with M2M communications and capable to use a short-range technology to connect with the gateway, in this case, the smartphone.

9.5.- Environments

For both environments, network architectures and communications between them will be proposed in order to meet as many patient's suggestions as possible. Although BAN will remain the same in both environments, it will be discussed within indoors system design.

9.5.1.- Indoors

Home monitoring will be done through some of the network architectures in 4.2. Principally, wireless BAN, PAN and LAN architectures are within the range of the indoor environment although usually PAN and LAN are not considered separately in most cases.

- **WBAN**

The short-range technology chosen to communicate the sensors deployed in the patient's body is ZigBee for the following reasons:

- Low power consumption
- Interoperability
- Full mesh network

Moreover, it may also be interesting to operate in the sub-1GHz ISM band to avoid interferences in the overexploited 2.4GHz ISM band. Thus, sensitive data will be protected against data corruption from interfering signals.

According to ZigBee architecture, the smartphone will act as the coordinator and sensors as end devices. Typically, the WSN will consist of 2 or 3 devices. In this case, a blood pressure monitor and a CGM, which is composed by an insulin pump and a glucose meter, all of them with wireless capabilities and connected to the smartphone. The idea is to provide a better lifestyle and comfort to the patients by freeing them from the constant manual measurements and injections of insulin.

- **WLAN**

Diabetes management is to be developed following SOA guidelines, so the applications will work regardless the WiFi standard available at the patient's home and most of the smartphones are compatible with all of them.

Indoor operation

In the WSN or WBAN, wireless sensors measure glucose levels and blood pressure, and transmit this raw data to the smartphone using M2M communication through ZigBee at regular intervals, which are to be defined by the doctor according to the state of the disease.

Monitoring application processes this data and translates into meaningful information, which is sent via WiFi to the personal computer a better visualization and storage. This new data is also transmit to a M2M server where patient's EHR is located in order to allow caregivers to access their medical history, helping both remote diagnosis and treatment.

When anomalous measurements are taken, the monitoring application must report them immediately to the doctor in charge and send an alarm message to the diabetic. If the insulin delivery device is an insulin pump, then the monitoring app can control the dosages remotely. It will be desirable to give some advice to address these potentially critical situations.

Naturally, the patients must have the possibility of accessing the collected data whenever and wherever they need through the smartphone, computer or any other electronic device with Internet capabilities.

Figure 9.1 summarizes the steps of the monitoring procedure. The sensors will capture raw data continuously and send it to the smartphone automatically and periodically. The smartphone, then, will do the same to the M2M server and the computer, and alert the patient when some inconvenience happens.

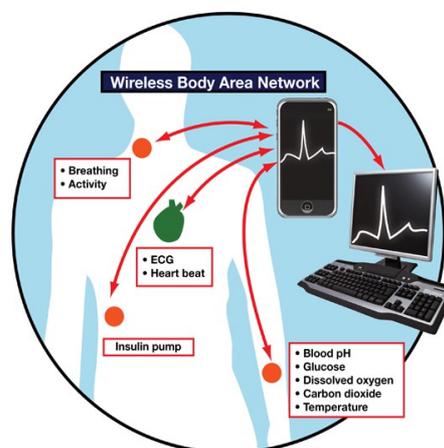


Figure 9.1: WBAN home system [35]

9.5.2.- Outdoors

Outdoors the situation changes slightly as the networks available escape from the control of the system designer. In this another environment, WBAN communications remain the same.

However, the smartphone operates as a gateway between WBAN and WWAN, and sends the data either via cellular networks or via data networks. Figure 9.2 shows the two possible ways of communication.

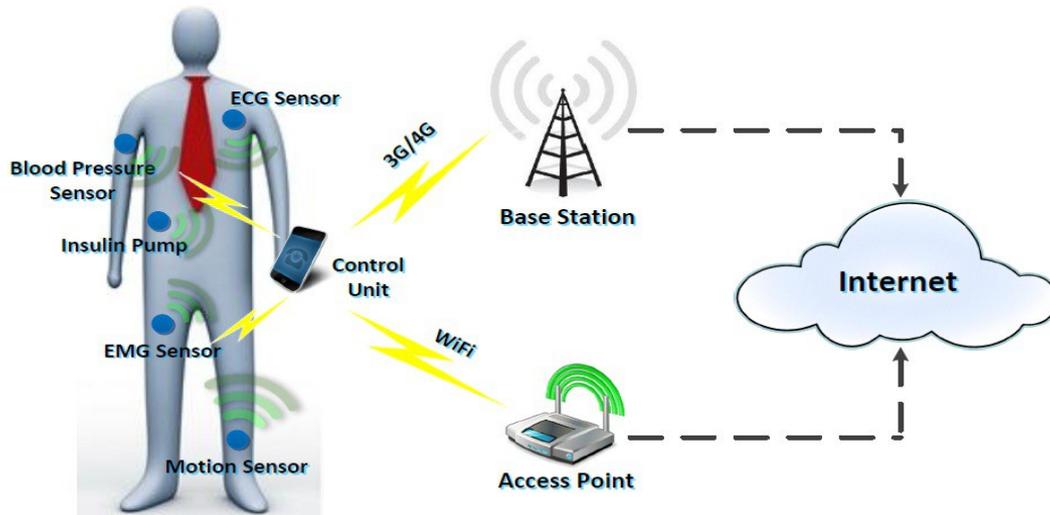


Figure 9.2: Outdoor system [36]

Usually, the communication will be through 3G networks as their coverage is more extensive than the one of WiFi hotspots or 4G. It is possible that in some places there is no coverage for data transmissions as in underground sites.

10.- Components and systems for sale

A component review is far beyond the scope of this project. For this reason, the following elements of the system are shown as examples in order to emphasize current technologies available for diabetes management.

First, purely medical components are analyzed. Then, mobile accessories and applications are pointed in short. Finally, specialized systems are briefly discussed. All the information in this section is taken from manufacturers' websites.

10.1.- Devices

Devices refer to sensor meters needed to measure vital signs and insulin delivery units. Within this category glucose control devices and blood pressure monitors are included.

10.1.1.- Glucose control devices

One example for each of the glucose control devices discussed in 8.3.1 is given, with some of their most important features in relation to the topic of this project.

- **Blood glucometer**

The Telcare BGM is a wireless glucose meter that automatically and wirelessly uploads a diabetic's blood glucose level to an online database, where caregivers, physicians and authorized people, like close relatives, can access the data through the company's website or through a mobile application for smartphones.

It is also possible to auto-sync Telcare BGM with special applications for diabetes, send personalized reports and receive medical feedback and coaching from the doctor. It enables to view all collected data in a PC.



Figure 10.1: Telcare BGM [37]

- **Continuous glucose monitoring**

Medtronic Continuous Glucose Monitoring system, MiniMed Paradigm REAL-Time REVEL SYSTEM, records glucose data every 10 seconds and transmits wirelessly the average reading to update the monitor every 5 minutes.

It also informs about the tendency of blood glucose levels, that is, whether rising or falling. Moreover, it is possible to set alarms up to 30 minutes before reaching glucose limits allowing early and fast reactions.



Figure 10.2: MiniMed Paradigm REAL-Time REVEL SYSTEM [38]

This system includes CareLink Personal Software. This software, which is compatible more than 25 of the most popular blood glucose meters, permits the patient to upload their data online for doctor's remote access. The data transmission is made by USB or serial connection from the CGM monitor to a PC.

Finally, a remote glucose monitor, called mySentry, can be especially helpful for monitoring children or family members with diabetes overnight, when they are most vulnerable.

- **All in one meters**

All in one meters combine a finger pricking device with the meter, rather than having the two as separate objects.

The Accu-Chek Mobile system uses a continuous test tape with 50 tests with a measuring time of 5 seconds approximately, a finger pricker and a lancet drum with six lancets stored hygienically and discreetly away, which makes it easier to test virtually whenever, wherever.

It has also a 2000 test memory with date, time and flags, and enables the recording of 7, 14, and 30 day averages. The user can individually program up to 7 standard daily reminders and 3 more which can be set to occur only once at some specific time after a test.



Figure 10.3: Accu-Chek Mobile [39]

The tests are simple as only 4 steps are required to perform them and the system included Accu-Chek software to view the results on a computer after transmitting the reports to the PC or PDA via a wireless connection.

10.1.2.- Blood pressure monitors

The Omron 10 Series+ monitor allows two different users to monitor and track their readings separately, plus guests can take their blood pressure without affecting the stored memory, which permits 200 memory storage (100 for each person).

A software that connects Omron monitor to a PC is included, so it is possible to keep a digital record of blood pressure over time. This connection needs a USB cable.

This monitor can also detect irregular heartbeats while measuring. However, it does not have mechanisms to contact medical staff automatically. It is the patient who must report any unusual event.



Figure 10.4: Omron 10 Series+ [40]

The monitor is equipped with automatic calibration, eight week history review and average reading based on three measurements per minute.

The Omron 10 Series+ monitor is compatible with Microsoft HealthVault³.

³ Microsoft HealthVault is a web-based platform from Microsoft to store and maintain health and fitness information

10.2.- Smartphone accessories

There is a growing variety of mobile accessories that allows the smartphone to become a medical device. For example, a blood glucometer or a blood pressure monitor. In this case, two accessories for Apple's devices are discussed but there are some other based on Android OS in the market.

10.2.1.- Blood glucose meter accessory

iBGStar is the first blood glucose meter to integrate blood glucose testing with a smartphone, only one running iOS 5. It is also compatible with iPod Touch.

Among the features of iBGStar, are a 6-seconds test time and a memory storage of 300 results. Besides, the meter is recharged similarly to a phone, which means there is no need to change batteries. Its dimensions, about 6 cm long and 3 cm wide, make it one of the smallest blood glucose meters available. Nevertheless, no alarm system is included in the device.



Figure 10.5: iBGStar Blood Glucose Meter [41]

A software application, called Diabetes Manager App, can be downloaded for free from Apple store. This application provides a variety graphical and statistical resources for a better control of the disease like 7-, 14-, 30- or 90-day summaries or storage of concrete past glucose readings.

The data flow from iBGStar to the iPhone occurs automatically each time the meter is connected and the application is running and it is possible to send the results to a healthcare professional via email from the application itself.

10.2.2.- Blood pressure monitoring accessory

Withings's Blood Pressure Monitor (BPM) allows to follow blood pressure recordings directly on an iPhone, iPad or iPod Touch running iOS 5 or superior. Once the BPM is wrapped around the arm and plug it into the iOS device, the patient can choose between several types of measurements, mainly single measurement or a mean average. Doctor's advice is recommendable for such an election. Then systolic, diastolic blood pressure and heart rate are displayed instantly in the screen and saved automatically in the iOS device.



Figure 10.6: Withing's blood pressure monitor [42]

Withings's BPM comes with a free app for iOS devices available on the App Store. This app lets the patient access and send measurements history to the doctor via email anywhere at anytime. It incorporates graphic tools for a better visualization of patient's evolution over time and is compatible with some service providers in e-coaching, e-health and e-fitness like Microsoft's HealthVault, for instance.

10.3.- Smartphone applications

Of the three types of applications recommended in 9.3.1 for the management of diabetes, those developed for patient monitoring are often part of a joint solution along with the measuring apparatus as seen in 10.1 and 10.2. For this reason, in this section only applications regarding diet and fitness will be commented. Both of them are meant to maintain a normal body weight. A selection of these kinds of apps could be found in [21].

10.3.1.- Diet applications

Tools to identify the calories and nutritional information of the food consumed, prepare healthy diets and track progress over time are within this category of applications. All the data can easily be shared with caregivers and selected family members.

10.3.2.- Fitness applications

A broad variety of personal trainer applications is available in the different platform's markets. The aim of this apps is to motivate the patient to lead a healthy lifestyle through sports practice.

10.4.- Systems

The final aim of any long-term disease managing system is to improve healthcare efficiency and its cost, while enhancing patient wellness. The solution presented here try to meet these objectives.

10.4.1.- AT&T and WellDoc DiabetesManager

WellDoc DiabetesManager is a system capable of coordinating diabetes type 2 care through self-management with real-time medical advice in order to achieve long-term wellness. Nowadays, WellDoc has developed and updated its platform to provide coverage for other chronic diseases.

This multi-disease platform is integrated into AT&T m-Health solution, which combines the services associated with WellDoc's DiabetesManager application and AT&T's system infrastructure capabilities such as highly secured storage, support and customer care.



Figure 10.7: AT&T and WellDoc DiabetesManager [43]

Full system operation is based on self-management and real-time data transmission and it is described in Figure 10.7. Patients are responsible for the capture of the relevant information using an enabled mobile device and then, the data is stored in such device and transmitted through any cellular network to a Cloud based analytic system, allowing both automatic feedback and caregiver's access to this data. This way, doctors may give medical advice at a distance when considered essential.

To sum up, the key characteristics of this close looped system are the following ones. First, patients must play an active role in managing their diabetes daily by collecting diabetes-related data and following medical advice in real-time. Second, doctors or any kind of caregivers are provided with live information about patient's status, allowing them to respond immediately to any complication and sometimes to prevent acute episodes. And third, online records may enable health stakeholders to stay connected in order to accomplish diabetic population studies, for example.

In addition to all of this, the solution has proven satisfactory clinical results in two different trials as it is referred in AT&T and WellDoc's websites.

11.- Conclusions

Throughout the text, the technical and medical aspects, which medical equipment and systems related to chronic diseases required, were discussed. Below the most representative results of this work are stated.

On the one hand, current technology allows addressing the most immediate challenges proposed by new models of chronic disease management. This technology enables real-time monitoring, direct contact between doctor and patient without having to visit the medical center or access to medical records from any device with an Internet connection anywhere, anytime.

However, mHealth is a very young industry and some big manufacturers attempt to obtain de facto standards prevents achieving interoperability, which is, otherwise, obviously indispensable for the establishment of this new health model.

Also, the benefits from the adoption of these initiatives appear straightforward in terms of savings for governments in the medium to long term, professional efficiency and comfort for patients.

These benefits entail certain compensations represented mainly by the need to understand the functioning of these initiatives by of all those involved in this new model. Governments or relevant medical officers must hit the target of the system so that the design fits their needs perfectly, while physicians and patients must learn to manage these new tools at their disposal.

Moreover, the lack of proven results on the feasibility and success of these solutions, together with the absence of national or international long-term plans foster uncertainty among investors, who lack the necessary information to assess the risks to which they are exposed.

In conclusion, and in summary, mHealth seems to have a promising future in the treatment of chronic diseases but not exempt from difficulties. Yet in the opinion of the author it is a risk that can be assumed.

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