Telemedicine Networks: Integrating Different Health Technologies towards a Common Goal

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Abstract. People like to live, work, travel and vacation in all kinds of places and weathers. Our active and inquisitive nature takes us to the most extreme locations, and our gregarious behavior allows us to coexist in both isolated as well as overcrowded communities. In all these scenarios, the new paradigm of healthcare becomes significant. The objective of this paper is to highlight the essential elements of both the current and emerging technologies that may constitute a ubiquitous, universal network of healthcare networks, providing an efficient and effective health service distributed globally. Our aim is to describe the current health ecosystem in order to identify the key agents and basic interactions that may contribute to conform a conceptual framework to provide ubiquitous health services using technology as an enabler but not the central objective. We propose an integral scheme that includes technology applications, regulation strategies and collaborative networks in order to provide efficient healthcare services anytime, anywhere, to anyone.

Keywords: telemedicine networks, wireless healthcare, healthcare coverage, eHealth, interoperability.

1 Introduction

Wherever we might be located at any moment, we carry our health and our illnesses along to all those places, and in case any accident or health issue may appear we expect to be efficiently attended and taken care of. Although many digital healthcare devices and services devices are currently available in several regions of the world, and Telemedicine technology helps a remote patient to be reasonably diagnosed, treated and supervised away from qualified physicians and hospitals, our mobile and nomadic nature requires ubiquitous healthcare attention, creating a very complex health challenge to the diverse healthcare systems around the world.

Commonly diagnosed and treated pathologies in some parts of the world may be totally unknown in other traveled places, often placing competent healthcare personnel in challenging situations. Another, often overlooked, problem arises with the increasing growth of natural origin disasters, such as earthquakes, hurricanes, floods or fires, with the capacity to damage or destroy health and medical infrastructure, as well as the electronic medical data of patients not stored in safe,

virtual environments: Are privately-owned, hospital-based, remotely-based or cloud-based health information storage systems safe? Most already-stored digital health information definitely is, but it remains to be seen if this stored information includes the totality (100%) of the health data (health & medical history; text, imaging & audio files; as well as laboratory studies), from all individuals (patients and their families), included into a single, openly compatible, Electronic Medical/Health Records (EMR/EHR), for a complete community, region or country. Even if this already secure health information is safe and available, it remains to be seen if it is also accessible from hospitals, clinics, ambulances, private practice medical or healthcare units, homes and nursing facilities for homecare assistance when necessary, as well as many other places that may require access to such medical and health digital information.

Universal health care and medical attention for the general population are not only considered a basic human right in many countries around the world, but also a reachable goal in many national administrations. Since this is a very complex problem that depends on many factors such as each country's health system, population, climate and territorial size, as well as its general work, economy and educational situation, among others, it requires a very careful analysis that considers the social, regulatory, medical and technological infrastructure available in that country or region.

The main purpose of any health system is to provide efficient health and medical service to a large number of individuals and, often, to their immediate families or relatives, through a network of health practitioners and professionals (physicians, nurses, health administrators, social workers, etc.). These health professionals work in efficient and qualified facilities, with the help of an increasing number of electronic, computing and communications devices. In order to integrate all elements of current and legacy healthcare systems into a digital globalized healthcare network. First, we must describe and integrate all existing and proposed elements of this framework, considering the current and future interoperability of all medical, technical, administrative and socio-economic segments of such complexity.

The aim of this paper is on the one hand to propose a general framework for the provision of universal digital health services. On the other hand, to identify the elements of the health ecosystem emphasizing the relevance of the interactions among their actors in order to support the design and deployment of medical quality services. The context will determine the nature and scope of the digital interventions. In this case, the understanding of the social reality of this context becomes crucial for the success of such interventions.

2   An Evolving Healthcare Framework

The basic proposal for a Healthcare Framework to provide a ubiquitous, global healthcare concept should include the service components shown in Figure 1. One way to address this problem, geographically speaking, is through the use of a diverse combination of networking technologies, considering mainly mobile and wireless

networks applied to healthcare purposes, which will interact with fixed networking technology already positioned in existing, legacy healthcare facilities. This technology combination needs to be fully compatible at the healthcare application level, but it must be also compatible at the lower layers whenever possible, with a maximized interoperability in mind and always considering access to the ubiquitous user or global traveler as mentioned by Brooks [1].
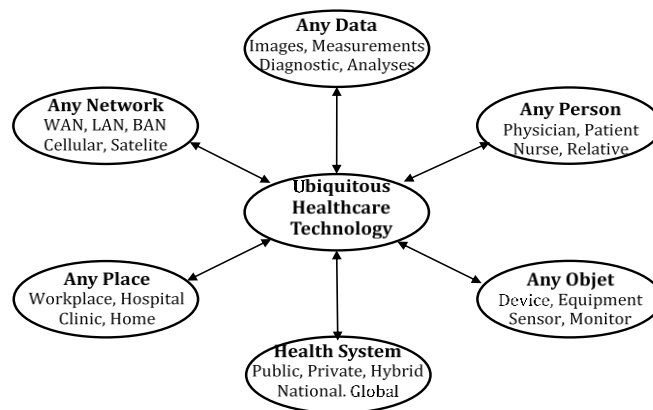

Fig. 1. Ubiquitous Healthcare Service Components

Our aim is to propose a preliminary framework conducive to develop specific strategies and lines of action towards the deployment of universal healthcare services. We expect this initial idea to be defined more precisely with participation of interdisciplinary cadres of scientists, physicians, technologists and healthcare practitioners who might also benefit by developing and creating new, or adapting existing or new technologies.

The prevailing health system in any country is usually a good indicator of that country's development and expected quality of life. This is especially important in rural and challenged settings for large or developing countries, but it is also found in urban settings at developed countries, where the existence and availability of qualified health personnel and facilities may be good, but its geographical distribution may be limited or even critical at times. In fact, Dussault and Franceschini mention in [2] that "A well-balanced distribution of infrastructures needs to go hand-in-hand with a well-balanced distribution of health personnel to be worth the investment, let alone to have an impact on the health of the population." They also report the presence of unemployed, underemployed or inactive medical and nursing personnel in urban areas, while having scarce and unfilled positions in rural facilities at the same time, due to several economic, social, cultural and professional reasons. They mention as justifying issues for this disparity such arguments as inadequate infrastructure, little physician's leisure time and other family-oriented aspects such as children's education and social activities. They even mention that "rural-to-urban physician displacement is usually compounded by public-to-private sector healthcare employment displacement" as it can be seen happening in most countries around the

world, regardless of the size and strength of their economies. Therefore, the uneven geographic distribution of qualified healthcare personnel is a common problem for small and large countries, as well as developed and developing regions around the world, therefore creating a complex dilemma not easy to solve.

The Organization of Economic Cooperation and Development (OECD) recommends a physician density of 2.3 health workers as average (2.2 physicians and 2.6 nurses) per 1000 inhabitants, while the World Health Organization (WHO) recommends a physician density of 3.4 skilled health worker per 1000 [3], and a minimum of 2.3 [4]. These figures are somewhat estimated since there are different criteria regarding professional and vocational health education and training around the world, as well as the regulations, activities, and tasks required for each health worker in order to work in different countries.

Even in highly developed countries, as well as in regions inside developing countries, there can be a similar kind of geographic irregularities regarding medical personnel distribution. There may be certain geographic urban areas in developed countries where the average local distribution of physicians may be much greater than the OECD or WHO recommendations, but also exist other areas in the same country where the physician distribution may be much smaller than the suggested average. The physician density figures published by the health authorities in each country are always an average and not always updated. Therefore, these irregularities always show up in a more detailed analysis [5].

Under this condition, the availability of telecommunications infrastructure with acceptable quality between both ends of the telemedicine link becomes significant. The existence of electric, electronic and computational equipment, as well as qualified personnel able to acquire, transmit, process and safeguard the digital medical information is also crucial. In the same token, we have identified the need to create the necessary didactic material, the desired electronic and printed books, manuals and references, as well as classroom and online presentations for capacity building.

The performance of telemedicine networks depends on the availability of efficient telemedicine systems whose objective is the delivery of digital healthcare services over distance in the form of medical data by healthcare professionals. In order to do this, it is needed to use Information and Communications Technologies (ICT) between the healthcare professional attending the remote patient and the distant healthcare professional at the medical or healthcare facility, over a communications link that works as part of a Telemedicine Network.

A very sensitive aspect on the handling of a patient's electronic medical data (EMR/EHR) is the threat of a cyberbreach in the aquisition, processing, storage or transmission and interconnection stages of a quality telemedicine service. The strong and secure regulation and enforcement of privacy and security laws and regulations is needed in order to provide security measures on health and medical networks, nodes, devices, equipment, personnel and services. With the increasing coverage of health services through the use of electronic and wireless technology, it is imperative that such networks provide availability, confidentiality and integrity on the provision of health and medical information to healthcare professionals and patients, while providing at the same time strong protection to that private personal health and

medical data from possible security breaches. Telemedicine security issues include authorization, authentication and accounting, common with banking and manufacturing applications among other industries, as mentioned in Garg and Brewer [6]. On the same subject, Olanrewaju et al. [7] emphasize the way protection and authentication of medical information and images matter in a telemedicine environment over electronic networks. Protection from undesired access, alteration and/or deletion of confidential health and medical information by intruders, hackers or plain criminals require the identification of loopholes and the implementation of privacy and security measures in order to identify, counter and defeat threats on security and authentication of medical records in telemedicine networks. Both papers [6] and [7] describe the main types of threats and attacks on telemedicine data such as electronic files and images, as well as eavesdropping and monitoring the continuous stream of data in order to illegaly collect private health information. Finally, a strong, wide-ranging, standardized regulatory framework with international reach is urgently needed for all wireless, mobile and satellite telemedicine networks, devices and applications.

From a systemic point of view, it is very important to define which device, service or application is found where in the telemedicine system, and how they are interacting with each other, so there will be a fluid and fluent transmission of information within the network. A basic telemedicine system has six main stages, as shown in Figure 2, where each stage may vary among many different options in its own way, depending upon its geographical, infrastructure or medical need.
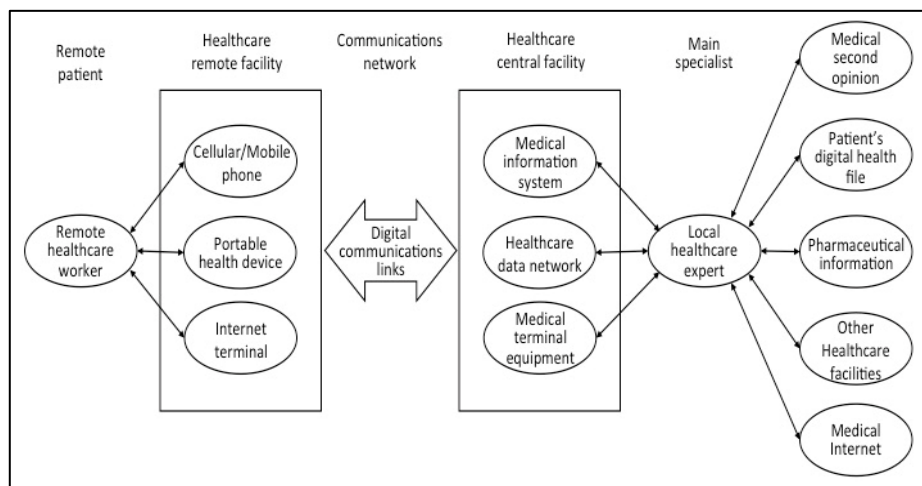

Fig. 2. Basic Elements of a Telemedicine System

The various options of each stage shown in Fig. 2 perform a specific function according to the related healthcare option, as follows:

1. Remote patient/healthcare worker: It is found at one end of the telemedicine service, usually where the remote patient and/or remote healthcare worker is found.

It will provide the patient's physiological health information to the healthcare worker, or to whatever digital device, terminal or communications system is to be used in the telemedicine service for each specific application or service related to a determined illness, health or medical situation.

2. Healthcare remote facility: This facility may be anything from a small measuring health device (electronic stethoscope, thermometer, microphone, image or video camera, computer or videoconferencing terminal) at the hands of a remote health professional, sent from a house, village, rural or small suburban clinic, up to a complex electronic o biomedical equipment that interacts with the patient.

3. Communications network: This is probably the most widely known part of any telemedicine or telehealth system since it is a legacy from the old analog telecommunication systems, now migrated to new digital, Internet-compatible technologies, such as wired, fiber-optical, mobile, wireless and satellite communications systems, ranging from a few meters up to thousands of kilometers apart.

4. Healthcare central facility: Once the remote patient's health data is effectively sent through a secure communications link, there usually is a main healthcare facility at the other end with the corresponding health and medical electrical interfaces to receive the incoming information the most similar possible to the one provided by the remote device or system at the initial end of the link.

5. Main healthcare specialist: This may be a medical expert, or group of experts, who will be attending the remote patient in a number of sessions, monitoring and/or evaluating the medical and health information remotely provided in order to prepare any kind of medical treatment and follow-up indications that may be deemed proper. Depending upon the type, content, and urgency of the medical information provided to this professional, a diagnosis and treatment will be programmed and executed, with the patient's cure, recovery, and well-being as the final goal in mind.

6. Telemedicine or Healthcare application: This final part of the telemedicine system is where a health or medical service or application may be provided though a simple file report (writing and filing electronic medical records), to an average (scheduled treatments, follow-up appointments, teleconsulting sessions, laboratory studies, medical/health files updates), or complex (access to other large medical teams, resources and institutions) process, including related information such as the indicated medicines and dosage, or any other clinical, pharmaceutical, laboratory analysis and report, as well as rehabilitation indications.

Therefore, a typical telemedicine system can be seen as a technical set of common, interoperable and compatible components, interfaces, protocols and systems, both in hardware, software and firmware form, and it must be clearly defined as a global, efficient, low-cost, high-quality e-Health system to be properly deployed, through the use of current and future telemedicine systems and networks.

Since each country has a different medical, technical, regulatory, economic and health system, these telemedicine technologies must be part of an interoperable, versatile, modular, and scalable technology oriented towards the medical sector,

similar to what the Open Systems Interconnection (OSI) model did for the development of the Internet during the 1980s and 90s.

3   Telemedicine Networks

Telemedicine systems usually operate inside the coverage area limits defined by their own telecommunications technology as indicated by Wager et al. [8]. When more than one communications link is used to interconnect several devices exchanging medical data using any communications channel, a Telemedicine Network is created. There are a substantial number of Telemedicine applications and networks operating in the world, with different applications and coverage areas using all kind of channels depending upon the technology used.

Sandhya Rani et al. mention a number of healthcare wireless technologies which use not only Horizontal Hand-Off (HHO) mechanisms to access mobile nodes with similar networks, but also describe Vertical Hand-Off (VHO) mechanisms to allow mobile node access to other heterogeneous access point connections, and describe several cases already considering Quality of Service (QoS) provisions for Telemedicine applications [9].
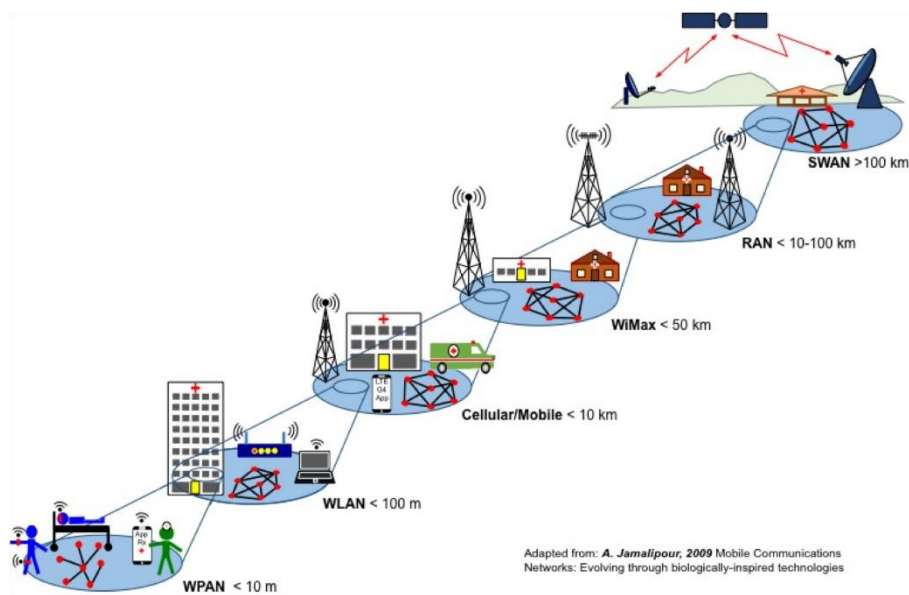

Fig. 3. - Telemedicine Networks, range and area coverage.

Wireless technologies cover all kinds of medical applications, from Bluetooth-based wearable ECG devices as part of a Body Area Network (BAN), to GSM, 3G or LTE mobile teleconsultation and ambulance-based bio-signals transmission, to Wi-Fi-based homecare monitoring and Wireless Local Area Networks (WLAN) clinic or

hospital-based supervision and managemenet, going all the way to Satellite-based earth stations to link far away, remote health facilities for Computer Tomography (CT) scanning and other medical imaging transmissions, as part of a Satellite Wide Area Network (SWAN), as shown in Figure 3.

Keikhosrokiani et al. [10] make a very thorough and concise description of the different wireless technologies and standards used in healthcare communications networks, covering practically all current technologies and representative healthcare and medical applications for wireless, mobile and satellite systems. Next there is a brief description of the main technologies and standards currently used in wireless telemedicine networks.

- Wireless Personal Area Networks (WPAN) are a family of networks designed around the use of the IEEE 802.15 Bluetooth standard in its varied forms: the IEEE 802.15.1 (Bluetooth Low Rate), IEEE 802.15.3 (Bluetooth High Rate) and Zigbee (IEEE 802.15.4 Low Rate) standards for wireless connectivity with fixed, portable and moving devices within a personal space (< 10 meter range). Casillas et al. [11] describe several Wireless Sensor Network (WSN) architectures over WPAN, and WPAN for healthcare applications, based on different available as well as propietary technologies for mHealth mobile patients with a number of bio-physiological variables in remote monitoring conditions, including a traffic capacity analysis.

- Wireless Local Area Networks (WLAN) are a family of networks designed around the use of the IEEE 802.11 standard in different PHY and MAC layers, initially developed for home and office applications such as Virtual Private Networks (VPN) and Voice over IP (VoIP). Its Wi-Fi version is probably the most used wireless networking technology in use today for broadband applications in homecare and hospital wireless networks for medical and administrative personnel, as well as visiting relatives and patient use.

- Cellular Mobile or Mobile Network is a mobile communications network where one end of the communications link is a mobile radio device inside a vehicle or carried by a person, while the other end of the link may be another such device or a fixed network connection to a public telephone or data network. Although initially developed and implemented for analog telephone service, since the 1990s it evolved to an all-digital telephone network first, and to an IP-compatible data network now. As mentioned above, [10] does an extensive description of several mobile technologies involved in healthcare.

- Worldwide Interoperability for Microwave Access (WiMAX) is an IP-based technology based on the IEEE 802.16 set of standards for wireless communications developed in the 2000s for the delivery of last-mile wireless broadband access as an alternative to cable and Digital subscriber line (DSL) over long distances, as mentioned in [12], and more recently with an interesting telemedicine case study in Ghana, described in [13].

- IEEE 802.22 Wireless Regional Area Network (RAN) is a standard for wireless communications networks aimed at the use of cognitive radio technology to provide wireless broadband access in rural areas between 10 to 60 km, and possibly up to 100 km in good weather conditions, from a Base Station (BS) to the Customer Premises

Equipment (CPE). Magana-Rodriguez et al. [14] describe a comparison between WRAN and WiMAX technologies for telemedicine applications in Mexico.

- Satellite Wide Area Network (SWAN) is a very large area data network, bounded by the limits on the coverage area, where it depends upon its antenna gain and directivity features, as well as its orbit around the Earth. It is usually based on the use of IP-compatible Very Small Aperture Terminal (VSAT) technology between the remote VSAT terminals and a central, large earth station (Hub) connected to the medical Internet. Kocian et al. [15] described the network parameters and user requirements of a hybrid satellite/terrestrial network for a European health project oriented towards the interconnection via satellite of a large number of remote and rural hospitals and health centers in several European countries in order to provide satellite telemedicine service. In another paper Saravanan describes how India, which currently has a large telemedicine program in service [16], provides satellite telemedicine services onboard an ambulance bus, a train and a rain flood water boat.

As it has been discussed, the seamless operation of a Health Network depends on technology factors as well as human and socio-economic aspects. In this respect, Rojas-Mendizabal et al. has proposed an e-Health ecosystem that integrates these key elements [17]. The different elements of the e-Health ecosystem, involving human, technology and socio-economic aspects, are described in Figure 4.
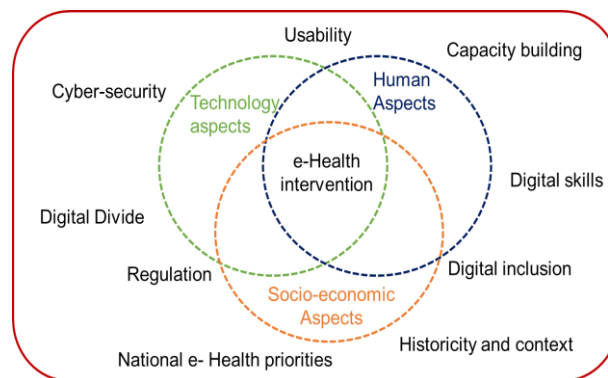

Fig. 4. Elements of an e-Health ecosystem

Rojas-Mendizabal explains in [18] the characteristics of the agents and their attributes in such ecosystem. The human aspects involve the participation of both the patient and the medical specialist. We take into account the digital skills regarding the understanding and adoption of the equipment on the part of the end-users.

The technology aspects consider the medical devices and their operational software and interfaces, as well as the performance of the telecommunications networks in place. The socio-economic aspects of this ecosystem include regulatory concerns, national health priorities, and the cultural and social reality of the particular context, among others. The insights of an in-situ external observer contributed to adjust the weights of the variables employed in the described simulation.

4   Conclusions

Emergent technologies such as Artificial Intelligence, Data and Analytics, as well as, Virtualization and the Internet of Things (IoT), to mention the most relevant, will play a fundamental role in the future provision of medical services. However, the operation of the Health Network is an essential factor to deploy these new applications. The new scenario of advanced applications such as personalized medicine and genomics will require robust, reliable and secure telecommunications channels. One important concern is related to the flow of personal data in Health Networks. Aspects of privacy, transparency, and exploitation of these data have called the attention of governments, academic and social civic organizations. The challenge of establishing adaptive and coherent regulation scenarios as well as strategies for ethical and moral development will play a fundamental role in the conformation of the future Health Networks. Technology is an enabler, but the center of attention must be the individual, the communities, and the institutions.

With a growing and increasingly nomadic population everywhere, ubiquitous health and medical attention with global reach is needed everywhere. The highly irregular geographical distribution of physicians, nurses and other healthcare professionals in both developed and developing countries, as well as the many different approaches to the development of public and private health systems, have created a plethora of new health and medical technology, not always compatible. Current and future wireless telemedicine networks are rapidly evolving, and current health technology allows addressing this problem in many cases, but differences in technical, operative, administrative and regulatory aspects among the different health technology systems and networks around the world difficult the adoption of common, interoperable standards, solutions and applications.

Emergent technologies such as Artificial Intelligence, Data and Analytics, as well as Virtualization and the Internet of Things (IoT), to mention the most relevant, will play a fundamental role in the future provision of medical services. Although these technologies will have a highly disruptive and positive presence in everyday life, their common denominator is the presence of current and future wireless networks everywhere, healthcare and medical networks included. Therefore, the efficient operation of a common Health Network with global reach is an essential factor to deploy these new applications. The new scenarios for advanced applications such as Personalized medicine and Genomics, among others, will require robust, reliable and secure communications channels. One important concern is related to the flow of personal data over current health and medical wireless networks, with weak or non-existent privacy protection regulation.

Aspects of privacy, transparency, and unauthorized access of these data have called the attention of governments, academic and social civic organizations, but a strong regulatory and standardized framework is urgently needed. The challenge of establishing adaptive and coherent regulation scenarios as well as strategies for ethical and moral development will play a fundamental role in the conformation of the future Health Networks. Technology is an enabler, but the center of attention must be the individual, the communities, and the institutions. As a final general framework for

this ubiquitous eHealth ecosystem, we propose the common development of an integral scheme that includes global wireless networking technology; efficient health and medical applications; specialized medical, nursing, health, administrative and engineering human resources; common, secure and compatible health technology regulation and standardization; and the development of collaborative and interoperable applications, devices, equipment, systems and networks in the health technology sector. If the above framework is reached and its components implemented, telemedicine networks and health technology will provide effective and efficient, ubiquitous health services to everyone, anywhere, anytime.

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