Smart Health: A Context-Aware Health Paradigm within Smart Cities


ABSTRACT

The new era of mobile health ushered in by the widespread adoption of ubiquitous computing and mobile communications has brought opportunities for governments and companies to rethink their concept of healthcare. Simultaneously, the worldwide urbanization process represents a formidable challenge and attracts attention toward cities that are expected to gather higher populations and provide citizens with services in an efficient and humane manner. These two trends have led to the appearance of mobile health and smart cities. In this article we introduce the new concept of smart health, which is the context-aware complement of mobile health within smart cities. We provide an overview of the main fields of knowledge that are involved in the process of building this new concept. Additionally, we discuss the main challenges and opportunities that smart health would imply and provide a common ground for further research.

INTRODUCTION

The adoption of information and communication technologies (ICT) within the healthcare sector led to the concept of electronic health (e-health), which is contributing to reduced costs and increased efficiency. Following the consolidation of e-health, the generalized use of mobile devices with positioning capabilities (e.g., smartphones) opened the door to the idea of mobile health (m-health). m-Health has extraordinary potential since it adds to the advantages of e-health with positioning capabilities (e.g., smartphones) opened the door to the idea of mobile health (m-health), which could be understood as the delivery of healthcare services via mobile communication devices. m-Health has extraordinary potential since it adds to the advantages of e-health with positioning capabilities (e.g., smartphones) opened the door to the idea of mobile health (m-health), which could be understood as the delivery of healthcare services via mobile communication devices.

Smart cities are strongly based on sensors that provide updated information about diverse variables, including temperature, humidity, allergens concentration, pollution, traffic conditions, and so on. According to Chen and Kotz [2], the context could be defined as “the environmental states and settings that either determine an application’s behavior or in which an application event occurs and is interesting to the user.” We understand these variables, provided by the smart city infrastructure, as being the context that helps us to understand the living environment of a citizen at any time. Thus, by properly using this information, we can provide citizens and patients with healthcare applications and services with active context awareness (i.e., applications and services that automatically adapt to discovered context) by changing the application’s and services’ behavior [2].

The main objective of this article is to coin the concept of Smart Health (s-Health) as the result of the natural synergy between m-health and smart cities, from the ICT perspective as well as that of individuals and society. We identify the main challenges and benefits implied by the new concept of health within smart cities, and discuss its feasibility in practice.

The rest of the article is organized as follows. The next section summarizes the main research fields that would play a key role in the development of s-health. Next, we describe our notion of s-health and emphasize its relevance, timeliness, impact, and feasibility. In the following section, we elaborate on the main challenges and opportunities that s-health implies. Finally, we conclude the article by providing a summary of our contribution and some final thoughts.
The Pieces of the S-Health Puzzle

s-Health is a natural complement to the concept of m-health within the context of smart cities that provide an extraordinarily rich context-aware environment. Due to the fact that s-health is a new concept, we can hardly analyze the state of the art. However, we provide the reader with a brief review of the main research areas related to it.

Smart Cities

The concept of the smart city has not been strictly defined, and can still be considered a vague idea. A definition of the concept is given by Caragliu in [1] and extended in Pérez-Martínez et al. [12] as follows:

“Smart cities are cities strongly founded on information and communication technologies that invest in human and social capital to improve the quality of life of their citizens by fostering economic growth, participatory governance, wise management of resources, sustainability, and efficient mobility, whilst they guarantee the privacy and security of the citizens.”

Pérez et al. (2013) [12]

Smart cities are an imminent need, and have recently received much attention from industry and academia. Private companies like IBM, Intel, and Siemens are investing in smart cities, and the scientific community has started to analyze them in detail [11]. The latest reports show that urbanization is progressing at an unprecedented pace. Currently, 50 percent of the world population lives in cities, and this percentage is expected to grow up to 70 percent by 2050. Thus, the development of infrastructures to address the needs of these huge amounts of people is urgent. Moreover, big city infrastructures need efficiency in many aspects, from energy consumption to resource allocation. Therefore, the only way for cities to provide sustainability and a good quality of life to their citizens is through “smart” interaction with them by using ICT to guarantee access to context-aware information.

Several cities have already started to work toward the adoption of the concept. Amsterdam has determined four areas (i.e., living, working, mobility, and public space) around the idea of sustainability, in which smart projects are conducted in order to improve the city. In Amsterdam, they focus on the reduction of CO₂ emissions, but we could find other examples that focus on other aspects as well. Some other examples of cities pursuing “smartness” are Vienna, Toronto, Paris, New York, London, Tokyo, Copenhagen, Hong Kong, and Barcelona.

The widespread adoption of sensors within smart cities provides additional interactions through people-centric, participatory, and opportunistic sensing [8, 9]. In this context a smart city becomes a huge system of systems, which has to provide citizens and local authorities with the processed information, in many cases personalized, that enables them to use the provided services on request, to manage cities and create the momentum for corrective actions.

Electronic and Mobile Health

With the promise of being helpful in addressing open biomedical problems, ICT have attracted the attention of the medical community. A collection of devices and complex systems with computers, sensors and databases are used in the so-called electronic health (e-health), which could be defined as:

“an emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the Internet and related technologies. In a broader sense, the term characterizes not only a technical development, but also a state-of-mind, a way of thinking, an attitude, and a commitment for networked, global thinking, to improve health care locally, regionally, and worldwide by using information and communication technology.”

Eysenbach, 2001 [4]

ICT might be used for a variety of health-related tasks, including communication between patients, doctors, and carers; distant provision of care; remote support to electronic diagnostic medical records; medication adherence control, and so on. ICT in the healthcare sector, if properly used, can significantly contribute to the reduction of management costs and increased efficiency. In this line, e-health substantially reduces the displacement of professionals and patients, globally brings down the cost of medical resources, and makes treatment and health watchfulness more comfortable to patients. All in all, e-health might be considered a revolution in this area. However, a probably more important revolution is taking place due to the use of mobile devices (e.g., smartphones): mobile health (m-health), which could be defined as the discipline founded on the use of mobile communication devices in medicine or, more specifically, the delivery of healthcare services via mobile communication devices; or:

“emerging mobile communications and network technologies for healthcare systems”

Istepanian et al., 2006 [5]

The use of mobile devices helps to perform tasks more efficiently. The remote monitoring of patients and communication between professionals, relatives, and patients will especially benefit from m-health. m-Health redefines healthcare services in three main aspects:

- It allows easy access to an unprecedented number of services and knowledge.
- It can be user-oriented.
- It can be personalized.

2 http://esa.un.org/unup

m-Health clearly extends the capabilities of indoor monitoring environments, and it is a powerful tool that allows the advance of several lines of research, such as the continuous assessment of the state of patients, early detection of emergency situations, detection of changes in health conditions, detection of abnormal situations, and

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Figure 1. Set diagram for the health and smart city planes. The relation/projection/intersection between the two planes is represented as the area of s-Health, and the numbers refer to the examples given within the text.

Privacy Protection and Security — Privacy is a fundamental right that has to be guaranteed. Within the healthcare sector, privacy issues are even more apparent than in other contexts. For example, the continuous monitoring of patients could be seen as an invasion of privacy, and it must be carefully considered in order to stop patients refraining from using that monitoring. Private information retrieval and anonymization techniques will play a key role in s-health.

Computer systems use passwords to identify and authenticate people. In order to gain security in the process of authentication, security protocols mainly based on public key cryptography have been widely used. In addition, biometric features (iris, fingerprints, ECG, etc.) are gradually being adopted. Also, technologies such as radio frequency identification (RFID) are used for identification of physical objects and people. Secure identification and authentication will be paramount for our s-health concept.

Other Related Fields — In addition to the aforementioned areas, the following are also related to the concept of s-health. A description of each area is beyond the scope of this article, however, for the sake of completeness we enumerate them: remote patient monitoring and supervision; data mining and knowledge discovery; information systems; databases and big data; trust and interoperability; telemedicine; ambient assisted living; and cloud storage security and privacy.

Smart Health

We are coining the concept of smart health as the natural complement of mobile health in the context of smart cities. We are witnessing how advances in ICT are being leveraged by the healthcare sector to create m-health, and by local and regional governments to foster the deployment of so-called smart cities. We can observe these two trends toward the adoption of m-health and the generalization of smart cities. Due to the fact that these two concepts are studied independently and deserve attention in their own rights, they have rarely converged into common points of contact. However, we claim that the infrastructure and technologies of smart cities could be leveraged and mixed with the concepts of m-health and telemedicine to create a novel and richer ubiquitous concept: smart health.

Figure 1 represents our concept of smart health. We distinguish two planes, the health plane and the smart city plane. Although those planes seem to be independent, when we logically project one over the other we observe an intersection that represents the provision of healthcare services with the infrastructure of a smart city. From this view we can derive the following definition for smart health:

“Smart health (s-health) is the provision of health services by using the context-aware network and sensing infrastructure of smart cities.”

According to this definition, smart health is a subset of e-health since s-health is based on the ICT infrastructure of a smart city. However,
smart health is different from m-health in the sense that the used underlying infrastructure might not be mobile at all; in fact, in many cases it might consist of fixed sensors. With the aim of clarifying the above concepts, let us refer to the following examples depicted in Fig. 2, which refers to the subsets illustrated in Fig. 1:

**Example 1 — Classical health.** This is a typical health-related activity, that is, a doctor visiting a patient with traditional tools (which do not necessarily involve ICT).

**Example 2 — e-Health.** This involves the use of electronic health records (EHR) and databases that store medical information of patients. This is a subset of classical health that uses ICT.

**Example 3 — m-Health.** An example is a patient checking her prescriptions from her mobile phone to guarantee medication adherence. This is a subset of e-health since it uses mobile devices to access medical data.

**Example 4 — S-Health.** A patient gets information from an interactive information pole to check the pollution level as well as the level of pollen and dust for which he has allergies. Thanks to this information, the patient can avoid areas that could be dangerous for his health condition. The information pole informs him about the best route to go, and where the closest pharmacies are to buy antihistamine pills.

**Example 5 — m-Health augmented with s-Health.** A cyclist wearing a bracelet with accelerometers and vital constants monitoring capabilities has an accident. The body sensor network detects the fall and sends an alert to the city infrastructure. When the alert is received by the system, the conditions of the traffic are analyzed, and an ambulance is dispatched through the best possible route. In addition, the traffic lights of the city are dynamically adjusted in order to reduce the time needed by the ambulance to reach the cyclist.

All in all, the main goal of smart health is to promote health to a higher position within society in a distributed, private, secure, efficient, and sustainable way by reusing the principles of m-health and smart cities in a convergent new paradigm of ubiquitous health.

With the definition and consolidation of the new concept of s-health, we allow the extension of the coverage of health from hospitals and adapted homes to everywhere in the city. Also, we provide the ground for the development of new techniques, models, interactions, and synergies that will contribute to the reduction of health costs, increased quality of life of patients, early detection of illnesses, collection of invaluable data for research, and the global improvement of our society as a whole.

**RELEVANCE AND TIMELINESS**

The increasing average age of people and the rise of chronic diseases will result in a dramatic growth in the need for assistance and healthcare within the years to come, especially in metropolitan areas where there is a higher concentration of inhabitants. There is an increasing demand for outpatient care, maintaining and restoring health, as well as maximizing the independence of patients and their relatives. Improvements in medical technology have helped people to live longer and with a better quality of life. Nevertheless, our societies are faced with new social and economic challenges due to the high expenses of welfare systems, and the increasing number of elderly and chronic patients. In the near future healthcare provision will change from centralized healthcare services, provided by doctors' offices and hospitals, to health monitoring based on ubiquitous and pervasive services. This evolution has two causes. First, there is increasing demand for better, more comprehensive and proactive healthcare, whose key component is the early-stage diagnosis of health issues provided by long-term and unobtrusive monitoring. Second, there is a need to mitigate the increasing healthcare expenses.

By providing health services in patients' homes, not only may the expenses decrease, but also, patients are provided with better quality of life. In addition, with the new concept of s-health, patients will also be monitored when they leave their homes using the infrastructure of the smart city, and new data will be gathered for their benefit and that of society.
S-HEALTH VS. M-HEALTH

The concept of s-health could be considered an augmentation of m-health with the sensing capabilities of smart cities. Actually, there are significant differences between them that justify the adoption of the new concept. While it is clear that the concept of s-health cannot be confused with that of smart cities, the differences with m-health must be highlighted. The main differences are the following.

**Differences in information sources:** The data used in m-health come from the patients. However, in the s-health approach the data are not only from patients but from a completely independent new source (i.e., the smart city sensing infrastructure). This new source of information surpasses m-health and justifies the appearance of the new concept of s-health.

**Differences in information flows:** m-Health is personalized (user-centric), while s-health is not only user-centric but also city-centric. This means that in m-health, data are collected from patients and processed, and the results go back to patients. However, s-health is not only user-centric but also city-centric since the information gathered by the patients also modifies the behavior of the city. For instance, in example 5, the fall of the cyclist changes the behavior of the city and leads to the modification of the traffic lights that allow the easiest arrival of an ambulance (clearly, this is beyond the scope of m-health).

**IMPACT AND FEASIBILITY**

s-Health focuses globally on society since everyone will become a patient during their lifetime, and we all participate in healthcare costs. In addition, we believe that it is important to define and clarify this concept now to drive the efforts of the diverse research communities toward a common and well defined concept of health from the very beginning of its development, thus averting unnecessary duplication and overhead in the future.

The concept of s-health is groundbreaking by its very nature and will result in a clear step forward. The proposed concept will have an impact in many senses.

**For society.** The generalization and adoption of the concept of s-health will benefit society as a whole. Improving healthcare services contributes to the creation of a healthier society, with healthier habits related to proper nutrition and physical activity within the sustainable and green philosophy of smart cities. Patients will greatly benefit from the concept of s-health since they will gain quality of life and independence, while their treatments become more efficient and cheaper. Also, we believe that s-health could contribute to the reduction of morbidity and mortality rates.

**For governments.** The adoption of the model of s-health we are proposing might significantly help reduce healthcare costs. Thanks to early detection and prevention mechanisms, patients will require fewer treatments. In addition, by using the infrastructure of smart cities, unnecessary duplicities are reduced, and deployed systems will be more efficiently used.

**For research.** The infrastructures and the concept of s-health along with the big data and cloud storage/ computing paradigms will allow the gathering of unprecedented amounts of data. These data are invaluable for the scientific community, which would be able to run experiments to gain knowledge on a variety of fundamental areas of human behavior, healthcare, engineering, and so on.

Regarding feasibility, the concept of s-health is a natural outcome of the mixture of well-known areas. Society has already accepted the concepts of m-health and smart cities; thus, it seems to be prepared to also embrace s-health.

**CHALLENGES AND OPPORTUNITIES**

**CHALLENGES**

The concept of s-health comprises a bewildering set of research areas that generally work independently. The adoption of the s-health paradigm by citizens requires the fulfillment of technological, financial, logistic, and psychological requirements [13]. The following is an indicative list of the main challenges that we envisage s-health will have to overcome.

**Multidisciplinary Research and Interaction** — All the areas described above are being studied worldwide by researchers and practitioners. However, it is pretty unusual for those researchers to work in the same institution; thus, it is much more difficult for them to share their knowledge to lead to interdisciplinary solutions such as the concept of s-health. Since this idea is new, there is a need for interaction and collaboration among many actors (governments, researchers, physicians, practitioners, etc.) to define common ground from the very beginning, thus avoiding unnecessary redesigns and over-spending.

**Security and Privacy** — Although s-health might help to mitigate many health-related issues, its ability to gather unprecedented amounts of information could endanger the privacy of citizens. Protecting privacy and securing the infrastructure is an inescapable challenge the research community is still struggling to address. Security and privacy protection is essential in almost every aspect of our lives. However, in the context of a smart city, it is even more important due to the fact that the gathered information is highly personal. From the data collected in a smart city, it would be possible to infer citizens’ habits, their social status, and even their religion. All these variables are very sensitive, and when they are combined with health information, the result is even more delicate. Thus, it implies a great challenge that is still to be studied in detail. Some attempts have been done to define the concept of citizen privacy and to provide ways of protecting it [10]. Also, many efforts are devoted to the protection of privacy in health; a representative project in this direction is Trustworthy Health and Wellness (THaW) [7]. THaW is aimed at solving several challenges to provide trustworthy information systems for health and wellness. Similarly, the Strategic Healthcare IT Advanced Research Projects on Security (SHARPS) project aims at advancing the...
requirements, foundations, design, development and deployment of security and privacy tools and methods for m-health. Those projects are in the edge of research and their challenge is formidable.

Sensor Integration— One of the main challenges in the implementation of scenarios in which ambient intelligence is supported, is to adequately account for the co-existence of heterogeneous systems. The system performance has a clear topological and morphological dependence from the location at which it operates. This last statement holds especially true in the case of dense urban locations, in which the main radio-electric phenomena are given by multipath propagation. In the case of body area networks [6], an additional element of complexity is added due to the presence and impact of the human body in the wireless channel. Also, privacy issues in the urban sensing ecosystem are a further research issue, only partially addressed thus far [3].

Big Data Management and the Cloud — Big data is generally defined by the 3Vs: variety, velocity, and volume. In a smart city these 3Vs are especially important, and they are even more relevant in the context of smart health. The data collected from the sensors are very diverse: temperature, pollution, allergens, and so on (variety); these data must be collected and analyzed almost in real time to provide a useful service to citizens (velocity); and the amount of collected data is huge since thousands of sensors take measurements every few seconds (volume). The huge amount of data that are collected in real time pose a tremendous problem in both bandwidth and storage. A possible way to approach this problem is by embracing the cloud paradigm. However, it is not straightforward to implement this solution since its scale has many implications for privacy, security, multi-tenancy, access control, and so on. In addition, the mining and analysis of this humongous amount of data is also a tremendous challenge for the artificial intelligence and statistics communities.

Usability and Human–Computer Interaction— How citizens interact with the city is an open issue to be solved. There are many problems to be addressed, such as designing better wearable and unobtrusive sensors, improving compactness and weight, increasing autonomy, simplifying interaction processes, making personalization easier, and improving reliability. Solving these issues is essential for the success of both smart cities and s-health.

Others— In addition to the above, Postolache et al. [13] identified other challenges in the adoption of pervasive healthcare: financial constraints, understating the complexity of the technological challenges, organizational issues, collaboration among all stakeholders (i.e., patients, doctors, therapists, sociologists, engineers, computer technicians), and the definition of proper quality audit processes and cultural aspects.

O P P O R T U N I T I E S

The concept of s-health is founded on the use of the infrastructure of smart cities, which opens a wide range of opportunities for the development of new health-related applications and services. The following is an indicative list aimed at illustrating the potential of s-health.

Data Collection, Presentation, and Analysis — Health-related data collection could be practically redesigned, since information, which nowadays is not considered, might become central to the provision of cutting edge health services. Real-time data could be collected from/by patients and healthy individuals, and combined with city data. Citizens’ vital signs, routes, and health records could seamlessly be integrated with data derived from ubiquitous sensors, cameras, weather reports, and forecasts. Proper use of such data could become the pillar of s-health applications.

Prevention and Management of Critical Incidents— s-Health will allow the accurate prevention and efficient management of chronic and acute diseases and accidents. Comprehensive s-health data can be used to identify situations requiring intervention (e.g., cardiovascular events, falls, accidents), and provide automated and optimized management of each incident, including provision of guidance and notification to authorities (Example 5). In the case of a mild incident, the patient could be guided to the nearest pharmacy or healthcare provider, while in life threatening situations, traffic information could be used to dispatch and guide ambulances. Comprehensive analysis of gathered data could provide multiple means for more efficient disease prevention, earlier detection of chronic illnesses, and even the identification of novel health threats and risk factors.

Effectiveness and Environmental Assessment— Patient monitoring data can be utilized to identify non-optimally managed cases or non-responsive patients to a given treatment and provide efficient assistance. For instance, s-health systems could identify chronic patients with vital signs contradictory to their prescribed medication (abnormal heart rate, blood pressure, blood glucose, etc.). Such data can be combined with a patient’s status, location, and current activities in order to reduce false positives and identify bona fide events requiring intervention. These applications might also have a significant impact on the assessment of novel interventions in clinical trials. s-Health systems could seamlessly integrate long-term patient monitoring, medical records, and efficiency assessment methodologies with city sensors’ data. This integration renders an optimal setting for the provision of high-quality personalized medicine. Environmental conditions (temperature, pollution, humidity, etc.) and patients’ daily routes and activities could be used to fine-tune dosing at an unprecedented level of detail, while the ability of the system to actively and routinely assess the effectiveness of each intervention could practically maximize all benefits.

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4 http://sharps.org/
Engaging Patients and Families in Managing Their Health — In s-health, the citizens are significantly empowered and efficiently assisted in order to actively participate in managing their health. s-Health systems can utilize medical records data and vital signs in order to provide optimal guidance for activities, habits, and everyday tasks within the city. For instance, an s-health application could provide patients with heart or respiratory problems with an optimal route by avoiding areas with high atmospheric pollution levels.

Improving Policy Decisions — s-Health systems could facilitate public health management. Policies and decisions can be “personalized” to each city and even district, based on data derived from population, health hazards, environment, climate, and available infrastructure. The opportunities arising from mining such data in order to optimize public health decision making are boundless.

Epidemic Control — s-Health data and methodologies can also drastically increase our efficiency in detecting and controlling epidemics. Citizens’ vital signs, locations, and activities could be used to detect probable new cases during an epidemic, efficiently identify areas of increased risk, and optimally manage a raging epidemic. Such methodologies can also be applied to the detection and management of other extensive health risks (e.g., pollution or radiation from an industrial accident).

Cost Saving — All the previously analyzed sectors might have a significant impact on healthcare cost reduction. Such reduction will also be accompanied by an increase of system efficiency and improvement of provided services. Timely, optimized disease management and prevention can lead to a reduction of unnecessary hospital visits and the emergence of acute events from poorly managed chronic patients. In addition, reduced time for action and efficient public health management could also provide optimal results while presenting cost reduction on a nationwide scale.

CONCLUSION

The widespread adoption of ICT in the context of cities has led to the appearance of smart cities. Similarly, the use of ICT and mobile technologies for health-related issues ended up with the provision of patient monitoring and health-care in a pervasive way through electronic and mobile health. While researchers are already shaping our future according to the established concepts of smart cities and m-health, we believe that there is a need for a new concept to which we refer as smart health (s-health), emerging from the combination of smart cities with electronic and mobile health services.

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