Chapter 2
Pervasive Computing and Healthcare

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Abstract A confluence of developments has led to the possibility of realizing a vision of pervasive healthcare. These include, but are not limited to, society becoming increasingly mobile, dramatic advances in various areas of technology and computer science, exponentially increasing healthcare costs coupled with workforce issues, the need to provide effective and efficient healthcare, and the change in the makeup of leading diseases most notably the increase in noncommunicable (or chronic) diseases. This is actually a very exciting time in healthcare delivery and one of the major challenges is to prudently adopt and implement appropriate pervasive healthcare solutions. To do this successfully, naturally requires a full appreciation of the key considerations in pervasive computing and healthcare; in particular, an appreciation of network healthcare operations. The objective of this chapter is to provide such a holistic perspective.

Keywords Pervasive computing · Ubiquitous computing · Pervasive healthcare · Network-centric healthcare

2.1 Introduction

The introduction to information communication technologies (ICTs) into healthcare contexts has led to increased access by healthcare providers and patients, more efficient tasks and processes, and a possibility for superior delivery of care (Varshney 2007, 2009; Kern and Jaron 2003; Wells 2003; Lin 1999; von Lubitz et al. 2006). However, contemporaneously we are also seeing an increase in the number of medical errors (US Institute of Medicine Report, o. J) as well as significant cost increases in all OECD countries (Zwicker et al. 2011), which provides significant stress on healthcare systems. In addition, we are also observing a growth in healthcare disparities and the quality of care (Chalassani et al. 2011) Moreover, other important trends include an aging population and a change in the makeup of leading disease and the exponential increase of noncommunicable disease (Wickramasinghe et al. 2011). Simply stated, providing superior healthcare today is indeed challenging.

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A possible solution appears to lie in the use of mobile and wireless technology (Varshney 2007, 2009; Wickramasinghe and Goldberg 2009). In particular, many have suggested that current and emerging wireless technologies (ibid) could improve quality of healthcare delivery both in urban and rural settings as well as decrease medical errors caused by poor or incomplete information. Moreover, in the area of chronic or noncommunicable disease, several scholars believe wireless technologies can provide superior patient self-care (Wickramasinghe et al. 2011; Wickramasinghe and Goldberg 2009). A vision for pervasive healthcare does indeed appear to be a reality and thus what is important is to understand some of the critical considerations that must be addressed in order to realize such a vision. However, it is the contention of this chapter that without consideration of a network-centric perspective, pervasive healthcare solutions will be unable to deliver their full potential benefits.

2.2 Background

Pervasive or ubiquitous computing (the latter term was coined by Mark Weiser in 1988) is fundamentally a postdesktop model of human–computer interaction in which information processing has been thoroughly integrated into everyday objects and activities. In the course of ordinary activities, someone "using" ubiquitous computing engages many computational devices and systems simultaneously, and may not necessarily even be aware that they are doing so. This model is usually considered advancement from the desktop paradigm and is defined as "machines that fit the human environment instead of forcing humans to enter theirs" (http://en.wikipedia.org/wiki/Ubiquitous_computing). Essentially then, ubiquitous is considered to be "... something that is available anywhere, anytime, while pervasive is something that is permeated in the environment" (Varshney 2009, p. 39); however, in the context of a vision for pervasive healthcare the two terms can be considered interchangeable and both are equally necessary to realize a pervasive healthcare vision. Specifically, there exist four major types or categories for pervasive healthcare; namely implantable, wearable, portable, and environmental (Varshney 2007, 2009).

Some of the immediate challenges in such a context include finding Internet use, supporting context awareness, providing energy access, and protecting privacy and trust (Varshney 2007, 2009). However, current successful initiatives include smart homes, mobile and ubiquitous telemedicine to support medical diagnosis, treatment and patient care especially in rural areas, pervasive patient monitoring services ranging from sensors to mobile phones to monitor particular criteria such as blood sugar for diabetes, or if someone has fallen especially in the case of an elderly individual, intelligent emergency monitoring, health aware mobile devices, pervasive life style management, and medical inventory management systems (ibid).

Taken together, on examination of these current pervasive healthcare initiatives, one cannot be criticized for categorizing them as an extension or subset of e-health; namely, as mobile health or m-health. The key is how to translate m-health into m-healthcare or m-care; i.e., to provide superior care using pervasive technology. To understand this, it is first necessary to understand e-health, its goal and purpose, as well as the doctrine of network-centric healthcare operations.

2.3 e-health

Today, there exist many definitions of e-health but essentially e-health involves the application of ICTs to support and facilitate the range of healthcare functions concerned with the practice and delivery of care (Varshney 2007, 2009; Zwicker et al. 2011). e-health; however, also includes the digitizing of various healthcare processes and tasks including e-billing, e-payment, e-prescription, e-radiology, and e-records (Varshney 2009). Healthcare systems throughout the world are implementing various e-health initiatives in an attempt to gain efficiencies in healthcare delivery and management, improve quality of care, reduce costs and medical errors, and provide more patient-centric healthcare (Zwicker et al. 2011).

Effective conduct of healthcare operations is not only extremely expensive, it is also extremely complex. In fact, most healthcare problems affecting the world have multiple roots involving social, economical, political, and even geographical factors whose combination provides fertile grounds for the spread of illnesses, prevalence of trauma, enhanced mortality, etc. (Akhtar 1991). As a remedy, it has been proposed that, instead of the currently practiced concentration on a specific devastating illness that captures public attention such as HIV/AIDS, a comprehensive "systems approach" offers the best approach to the solution the causative factors of global healthcare problems (Akhtar 1991). Presently, the governments and political bodies of both European Union and of the United States begin to view the "systems approach" as the only viable option (European Institute of Medicine 2003; National Coalition on Healthcare 2004; Kyprianou 2005).

The introduction of ICT into healthcare delivery has changed many aspects of medicine; however, the explosive growth of worldwide healthcare costs indicates that a mere introduction of advanced technology does not solve the problem (von Lubitz and Wickramasinghe 2006b; Onen 2004; Olutimayin 2002; Larson and Society of General Internal medicine (SGIM) Task Force on the Domain of General Internal Medicine 2004). The quest for financial rewards provided by the lucrative healthcare markets of the Western world led to a plethora of dissonant healthcare platforms (e.g., electronic health records) that operate well within circumscribed (regional) networks but fail to provide a unified national or international service (Onen 2004; Olutimayin 2002; Larson and SGIM Task Force on the Domain of General Internal Medicine 2004). In addition, there is a striking lack of standards that would permit seamless interaction or even fusion of nonhealthcare (e.g., economy or local politics) and healthcare knowledge creation and management resources. Thus, despite the massive amount of information that is available to healthcare providers and administrators, despite availability of technologies that, theoretically at least, should act as facilitators and disseminators, the practical side of access to, and the use and administration of healthcare are characterized by increasing disparity, cost, and burgeoning chaos (Larson and SGIM Task Force on the Domain of General Internal Medicine 2004).

Previous work by von Lubitz and Wickramasinghe (Akhtar 1991; von Lubitz and Wickramasinghe 2006a, c) discusses the general principles and applicability of the military concept of network-centric operations and its adaptation to modern worldwide healthcare activities. Succinctly stated, the doctrine of network-centric healthcare operations is defined as "unhindered networking operations within and among the physical, information, and cognitive domains that govern all activities conducted in healthcare space based on free, multidirectional flow and exchange of information without regard to the involved platforms or platform-systems, and utilizing all available means of ICTs to facilitate such operations" (Akhtar 1991, p. 334). The three domains include the (Akhtar 1991):

1. *Information domain*: Contains all elements, which are required for generation, storage, dissemination/sharing, manipulation of information, and in addition its transformation and dissemination/sharing as knowledge in all its forms.
2. *Physical domain*: Encompasses the structure of the entire environment healthcare operations intended to influence indirectly or directly—political environment, fiscal operations, patient and personnel education, etc.
3. *Cognitive domain*: Relates to all human factors, which affect operations—education, training, experience, motivation, and intuition of individuals involved in the relevant activities.

The proposed network-centric healthcare operations are conducted using a World Healthcare Information Grid (WHIG)—a multidimensional communications network connecting all relevant information acquisition entities (sensors) with information processing, manipulating, and disseminating organizations (nodes). The nodes also serve as knowledge gathering, transforming, generating, and disseminating centers (Fig. 2.1).

At the highest level of complexity, healthcare activities are characterized by multidirectional and unrestricted flow of multispectral data deriving not only from research/clinical/administrative sources but also from fields that may appear to be almost entirely unrelated—economy, politics, social structure, etc. (Akhtar 1991). At the interdisciplinary level, the data exist as highly incompatible entities the access to which is frequently virtually impossible. In network-centric operations, raw data, information, and node-generated knowledge exist in fully compatible formats based on standards that allow automated meshing, manipulation, and reconfiguration. Essentially, network-centric healthcare operations are based on the principles of high-order network computing, with the WHIG serving as a rapid distribution system, and the nodes as the sophisticated processing centers whose task is to act as integrated data-/information-/knowledge-generating sites and DSS/ESS platforms providing high-level, query-sensitive network-wide outputs. The nodes are also capable of extracting and analyzing data and information from healthcare-relevant sensors and electronic data sources (e.g., financial, political, military, geological, law enforcement, infrastructure level, etc.), meshing complex inputs into knowledge blocks relevant to both specific and general healthcare issues. Incorporation of

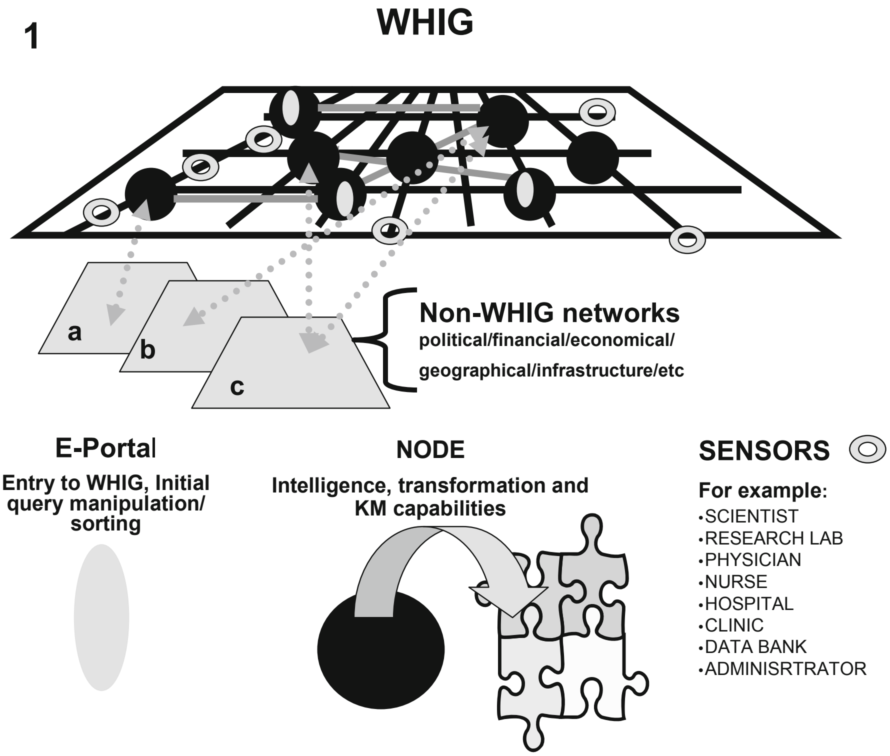

Fig. 2.1 Schematic diagram of a WHIG segment. Sensors feed raw data/information into the network through network-distributed portals. Likewise, data, information, and knowledge queries enter through portals as well. The latter provide entry-level security screening and sorting/routing. Subsequent manipulation, classification, and transformation into information/pertinent knowledge is executed by interconnected nodes. Whenever required, each node can access information/knowledge existing within non-WHIG networks and databases and compare/merge the contents with the contents existing within the WHIG. (Adapted from von Lubitz et al. 2006)

external information in healthcare operations is not only necessary but often critical element that will ultimately determine success of either planned or conducted activities (Olutimayin 2002; Larson and SGIM Task Force on the Domain of General Internal Medicine 2004). The complications resulting either from the failure to include elements external to the essential healthcare activities or consequent to the exclusion caused by either by sheer ignorance or by incompatibility of information/knowledge resource platforms have been amply demonstrated on several occasions (von Lubitz and Wickramasinghe 2006a, c).

The theoretical foundations for the activities characterized by a broad range of multidisciplinary (multispectral) inputs have been synthesized by Boyd as the OODA Loop (Boyd 1987; Akhtar 1991; Larson and SGIM Task Force on the Domain of General Internal Medicine 2004; von Lubitz and Wickramasinghe 2006a) whose practical applications ramify from military activities to global financial/banking operations, lean manufacturing, just-in-time supply chains, medical training, etc. The rules described in Boyd's (OODA) Loop apply particularly well to major international healthcare programs that are often executed in a highly fluid, ultracomplex environments that demand not only rapid, reliable sampling of the environment (data/information collection) from a broad variety of sources but also a very high degree of automation at the subsequent levels (manipulation and classification into larger information/germane knowledge entities.) Contrary to the prevalent platform-centric operations, network centricity allows vast increase in sampling speed, range, and data manipulation speed. Consequently, decision supporting outputs of the network are faster, more situation/operational environment-relevant and, most importantly, allow robustly elevated rate of stimulus–response cycle. Moreover, by increasing reaction relevance and speed, network-centric operations facilitate goal-oriented manipulation of the operational environment and also increase both the level (accuracy) and predictive range of responses to environment-induced pressures. However, in order for such interactions to happen, a well-integrated international system of multitype telecommunications must be in place. While the development of such an umbrella system can be conducted with the greatest ease among the Western countries, it is far more complex among the Less Developed World. The task is, however, not insurmountable and the frequently raised arguments of prohibitive costs or nonexistent knowledge support at the local level may not be entirely true. Moreover, we only need to look at the infrastructures that support modern banking to see that not only is this possible, it can happen on a global scale.

2.4 Summary

Returning to the specific context of pervasive healthcare or m-health, what becomes important then is to incorporate a holistic perspective, i.e., a network-centric perspective into the design and development of any pervasive healthcare intervention. If such a conceptualization occurs, only then will it be possible to provide anytime, anywhere for anyone healthcare delivery that subscribes to a healthcare value proposition of excellence in access, quality, and value. The idea of network-centric healthcare operations may seem at first futuristic and unrealistic; but a question we do need to ask ourselves is can we afford to continue down the track of ineffective, inefficient, and costly healthcare initiatives or should we begin to develop a superior solution?

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