J Med Syst (2011) 35:1431–1445
DOI 10.1007/s10916-009-9420-4

ORIGINAL PAPER

Towards the Systematic Development of Medical Networking Technology

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Received: 12 November 2009 / Accepted: 10 December 2009 / Published online: 6 January 2010

Abstract Currently, there is a disparity in the availability of doctors between urban and rural areas of developing countries. Most experienced doctors and specialists, as well as advanced diagnostic technologies, are available in urban areas. People living in rural areas have less or sometimes even no access to affordable healthcare facilities. Increasing the number of doctors and charitable medical hospitals or deploying advanced medical technologies in these areas might not be economically feasible, especially in developing countries. We need to mobilize science and technology to master this complex, large scale problem in an objective, logical, and professional way. This can only be achieved with a collaborative effort where a team of experts works on both technical and non-technical aspects of this health care divide. In this paper we use a systems engineering framework to discuss hospital networks which might be solution for the problem. We argue that with the advancement in communication and networking technologies, economically middle class people and even some rural poor have access to internet and mobile communication systems. Thus, Hospital Digital Networking Technologies (HDNT), such as telemedicine, can be developed to utilize internet, mobile and satellite communication systems to connect primitive rural healthcare centers to well advanced modern urban setups and thereby provide better consultation and diagnostic care to the needy people. This paper describes requirements and limitations of the HDNTs. It also presents the features of telemedicine, the implementation issues and the application of wireless technologies in the field of medical networking.

Keywords Systems engineering · Hospital Digital Networking Technologies · Health care divide · Wireless technology

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Introduction

The term hospital network describes a group of hospitals that work together in order to coordinate and deliver a broad spectrum of services to the community [1, 2]. A health care system comprises of two or more hospitals owned, sponsored, or contract managed by central organizations. Most of these health care systems follow allopathic or modern medicine (Western medicine) [3]. Furthermore, there is a variety of other healthcare practices available these days [4] and people

follow either one, or a combination, of these practices for a healthy living.

There are also personalized health care medical practices [5, 6] in operation today that are designed to treat individuals based on their specific genetic code. This is done in order to provide a tailored approach to treating the ailments of patients. These practices use preventive, diagnostic, and therapeutic interventions that are based on genetic tests and family history information. The goal of personalized health care is to improve the overall health of the population.

Thus, healthcare to people, living in both urban and rural areas, should be appropriately and effectively delivered using at least either western or alternative practices. Such an efficient health care delivery system requires the use of digital networking technologies for connecting the urban and rural areas and the various hospitals and diagnostic centers around the globe. These networking technologies, which are used in hospital setups, are called *Hospital Digital Networking Technologies* (HDNT). They can prove to be very efficient in providing healthcare services to even the remotest part of the world.

For example, Aanestad and Hanseth introduced new non-desktop technologies into a complex medical work practice (surgery). Using actor-networking technology, they argue that conceptualizing the process as cultivating the hybrid collective of humans and non-humans, technologies and non-technologies is a suitable and useful approach. Following their line of thought, this concept may capture the open ended and emergent nature of the process and indicate the suitability of an environmental approach [7].

Other research work focused on the design of the so called ECHONET (EchoCardiographic Healthcare Online Networking Expertise in Tasmania) system—a telemedicine system developed by CSIRO (Commonwealth Scientific Industrial Research Organisation) Australia. It aims to facilitate the sharing of expertise and services between the Intensive Care Units of a major tertiary hospital and a remote hospital in Tasmania, Australia. The baseline study, which was conducted alongside this project, was used to evaluate the ways in which the Action Research approach influenced the project directions and its success. This gave valuable information to the project team; it provided the basis improve the system such that the clinicians' needs are more adequately met [8].

Research and development moves ahead and there is even a perception in modern society that technology is a solution for all problems. However, this conclusion is not quite correct. Technology, not properly designed, tested and integrated into an organization or business does not serve its purpose. Therefore, there is an urgent need to ensure that the HDNTs developed for hospitals are designed according to the needs of the stake holders of the system [9, Chapter 16].

The primary aim of this paper is to give a basic insight into the ways in which the computer and communication technologies can be used to connect medical facilities centered in urban areas to the majority of people who still live in rural areas. We tackle the health care divide problem with a systems approach [10]. Thereby, we follow the ideas of Ramo and St.Clair, who asked such provocative questions like: "If we can record the heartbeat of an astronaut ten thousand miles above the earth, then why can we not readily provide superb medical monitoring for the bed patients of our hospitals?" [11]. Questions like these form the anchor point for their discussion on systems thought. The argument is that there is no perfect solution for large scale problems; however there are multiple optimal solutions. The multitude of optimal solutions arises from the fact that a multitude of system properties can be measured in different ways. The first step to overcome this problem is to gather information about the problem itself, the environment the system has to operate in and current technical solutions. This information enables us to state the goals of the system. A second step outlines concrete properties which enable the system to meet these goals and it proposes measures and measurement guidelines. These measures, which are taken according to the measurement guidelines, indicate to which level the properties were archived. Having such a list of properties and measures enables a group of technologists to implement the system. This implementation must pass various tests. These tests must be designed such that they establish trust in the implemented system.

In general, the systems thought in the area of engineering leads to the systems engineering methodology. This methodology ensures that the correct technical tasks get done during development through planning, tracking, and coordinating [12]. The system design steps, outlined in the previous paragraph, are not isolated from each other. The way in which these steps are related to one another depends on the individual systems engineering methodology, which was adopted for the design. For example, the National Aeronautics and Space Administration (NASA) systems engineering handbook [13] outlines sophisticated checks and balances which govern the information flow between the individual steps and the transition from one step to another.

The structure of this paper reflects the systems engineering methodology, which lies at the center of this

work. Before a technological solution, i.e. a HDNT system can be discussed, it is necessary to understand both the nature of the problem and the environment in which a system, which solves the problem, must operate. Both points are covered in the requirements analysis presented in Section "Requirements and specification". This section states also the goals for the proposed HDNT system. Section "Implementation" moves the argument on to implementation aspects of HDNT systems. In this section we make the case for wireless networks in the area of health care. Both requirements and implementation are discussed in Section "Discussion". The paper concludes with Section "Conclusions".

Requirements and specification

This section documents the results of the requirements analysis for the HDNT design. This requirements analysis starts with understanding the background of the problem. Therefore, Section "Health care systems" discusses different health care systems. The data, which manifests our primary problem of the health care divide, is analyzed in Section "Data analysis". Based on the data analysis results, we make the case for the need of medical networking in Section "The need for medical networking". The limitations of current HDNT technologies and the security issues involved with it are presented in Sections "Current limitations of HDNT" and "Security in medical networks", respectively. Based on both data analysis results and current limitations, we formulate the requirements of HDNT system in Section "Requirements of Hospital Digital Networking Technologies (HDNT) ". The goals, stated in Section "Goals of an HDNT ", provide a more abstract interpretation of these requirements. Finally, Section "Specification refinement" refines the requirements into a system specification.

Health care systems

Some alternative health care systems are in fact traditional medical systems, which, in the early twentieth century, were considered incomprehensible, cryptic and masked in mysticism. These systems are now gaining acceptability all over the world as alternative lines of treatment. Some of these systems are also being integrated into mainstream health care systems as complementary systems. The list below sets western medicine alongside a few very popular and widely followed traditional systems of medicine which were practiced before the advent of modern medical practices.

1. Western Medicine: Western medicine stands in the Greek tradition. However, by using modern scientific biomedical research it has risen above its herbalist traditions [14]. Western medicine follows strict clinical practice where doctors personally assess patients in order to diagnose, treat and prevent disease.
2. Ayurveda: Ayurveda or ayurvedic medicine is an ancient Indian system of health care. Its origins are traced to around 1200BC. It is native to the Indian subcontinent and it is commonly used in neighboring countries like Nepal and Srilanka. Ayurveda, literally means the science of life, it aims at healing the individual as a whole, instead of merely at the molecular level. Ayurveda is a holistic system of medicine which promotes healthy living along with therapeutic measures that relate to physical, mental, spiritual and social harmony [15, 16].
3. Siddha: is a form of south Indian traditional medicine and it is one among the trio of Indian medical systems - Ayurveda, Siddha and Unani. It is believed to be the oldest medical system on earth. The human body is considered to be a conglomeration of three humors, seven types of body tissues and waste products. This system is believed to have been invented by 'Siddhars', the ancient supernatural saints of India who in turn received this knowledge from lord Shiva, the Hindu God [17–19].
4. Unani: Unani medicine (originated in Greece during 460–377BC) is based on the theory of four bodily fluids or humors, with each humor leading to a specific temperament in a human being. The four humors are phlegm, blood, yellow bile and black bile. The term Unani is used to refer to Graeco-Arabic medical system which is based on the teachings of Hippocrates, Galen and Avicenna (Hakim Ibn Sina) [19–21].
5. Naturopathy: is a system of medicine which emphasizes the ability of the body to heal and maintain itself. Naturopathic practitioners prefer to avoid the use of invasive surgery or synthetic drugs and prefer to use natural remedies like herbs and fruits. Thus, it is based on the practice of applying simple laws of nature to cure diseases. Breathing exercises which induce relaxation and well being and meditation are used to promote positive health and well-being. These are also helpful in assisting the body to overcome certain illnesses [22, 23].

6. Homeopathy: Homeopathy lays emphasis on strengthening the immune system. Homeopathic practitioners contend that an ill person can be treated using a substance that can produce, in a healthy person, symptoms similar to those of the illness. Homeopathy was conceived by Samuel Hahnemann in the early years of the nineteenth century. It quickly became popular in Europe and America. Its popularity in these countries has declined with the advent of modern medical practices based on allopathy. However, it has a large following in India offering degrees in homeopathic medicine [24, 25].

Data analysis

The number of doctors available per one thousand people can serve as a quality measure of health care services, which are available to the people of a country. For example, in the USA this figure is 2.6 doctors for every 1000 people. This figure is a respectable 2.31 in the UK and drops to 0.28 in a developing country like Bangladesh. The world average is 1.31 doctors for every thousand people. Table 1 details the approximate availability of doctors per 1000 people in developed and developing countries. Migration of trained doctors from developing to developed countries is further lowering the availability of doctors to the general population in the former.

In addition, it is observed that there is disparity in the availability of doctors in urban and rural areas in developing countries. For analysis purposes, consider the situation in India. About 72% of doctors work in urban areas, serving about 30% of the population. The remaining 70% of the population is served by the remaining 28% of doctors. Thus, while world class health care is available to a few wealthy citizens in urban centers, the rural poor are deprived of even elementary health care. Such a situation exists in almost all developing countries.

Table 1 Approximate availability of doctors per 1000 people in developed and developing countries

Country	Number of doctors per 1000 population
USA	2.6
UK	2.31
China	1.1
India	0.61
Bangladesh	0.28
World average	1.3

The need for medical networking

There are a number of charitable hospitals providing free medical treatment to the patients in developing countries. The Sai Medical Institutions, run by Sri Satya Sai Baba group in Bangalore [26], and the Amrita Institute of Medical Sciences, run by the Mata Amritaanandamayi group in Kochi [8], are a few examples of such hospitals in India. Though, there are many other similar institutions, they are far fewer in number, given the size and population of a country like India. While the government must encourage the initial setup up of charitable hospitals, which can make the cost of health care affordable to the common man of modest means, this alone will not solve the problem. A technological solution, which can bridge the gap between people living in remote areas and the specialist doctors practicing in big cities, is needed. To address this issue, the concept of telemedicine was developed. It is a rapidly developing technology where patient information is transferred between a network of hospitals and diagnostic centers via communication and networking technologies for the purpose of consultation, treatment decision making, and sometimes even to assist in remote medical procedures or examinations.

Current limitations of HDNT

Currently, there are certain limitations in both availability and implementation of networking technologies in the medical field. Some of these are listed below.

1. Improper network design and implementation.
2. No fool proof protection against misuse of medical records.
3. Use of pirated software.
4. Lack of training of personnel which prevents the tool from being utilized properly.
5. If we study the history of science and technology, we will find that the basic axioms of mathematics have not changed while newer and newer branches of mathematics have opened up. In other sciences like physics, more general and complete theories have replaced earlier ones. For example, the theory of relativity includes Newtonian mechanics as a special case. Similar developments have occurred in medical as well as in computer and communication science. As a result of these developments, new instruments are constantly being developed, data/video formats and hardware specifications are also undergoing constant change. Some of these

have to be upgraded / changed every two or three years. Most of the software supplied, which is for any application (not necessarily medical networking) is in operation for a few years. Afterwards, there is a need to upgrade to a new version, maybe upgrade to a new operating system which may be designed for a new hardware architecture. In this case, the hospital may have to upgrade the hardware as well.

6. The formulations used in the allopathic system of medicine are developed after a great deal of study and the execution of extensive clinical trials. However, a lack of standardization is seen in medicines prescribed by practitioners of alternative medical systems. The medicines prescribed by their text books should be identified and analyzed. The medicines and treatment protocols should be put through clinical tests before releasing them into the market. A great deal of research work is under way in this field to standardize these medical formulations. However, more work is required before the public can repose the same degree of confidence in these formulations as they do in the case of standard allopathic medicines.

Security in medical networks

When it comes to using modern technologies, such as HDNT, there are a variety of risks involved. Currently, the biggest risk comes from the fact that it is difficult to ensure information security over the internet. Hence, the design and implementation of information security is an important parameter in medical networking systems. Designing secure systems involves the right knowledge of hardware, operating system, communication path, type of information to be transferred and the protocols that handle information transfer. In the United States, any kind of medical data transfer via a computer network requires that Health Insurance Portability and Accountability Act (HIPAA) [27, 28] compliance is ensured. Further, the ANSI X.12 [29] standard must be followed as well. The design of the medical networking system should focus on specific security issues concerning both application and communication security.

Furthermore, the internet is an open medium which is accessible to everyone and the availability of online questions and answers might tempt people to resort to self medication, which is not a good practice. Hence, proper protocols should be framed to ensure the reliability of the health-related data that is published on the internet. Furthermore, the public should be well informed about the problems arising out of self medication.

Requirements of Hospital Digital Networking Technologies (HDNT)

The typical hospital is a large complex of people, equipment, material, and information flow. Business, logistics, accounting, and medical test data are moving about. Training and treatment coexist. Patients, interns, doctors, nurses, visitors, accountants, orderlies, medicines, towels, and X-ray machines weave in and out of a busy mountain of activity. Exceedingly sophisticated activity is intermixed with the many specialized and mundane aspects of keeping a facility involving many people and things going smoothly. To aid this activity a number of technological innovations are taking place in the medical domain. Novel and sophisticated diagnostic instruments are being designed, methods of diagnosis are changing (non invasive diagnosis tools are gaining popularity), doctors are seeking second opinions from their peers over the internet and online communication between the same groups of hospitals across the globe is taking place. There are a variety of networking strategies available to design a medical network. In order to help the readers understand and better visualize the features, requirements and limitations of medical networks in general, one of the many available network architectures has been illustrated and described in this section. In this medical networking architecture, remote data transfer has been achieved using geostationary satellites. It is felt that connecting hospitals, doctors and patients across the globe between countries can be efficiently done using single hop satellite links using either the X band (9–12 GHz) or the Ku band (12–18 GHz). A block diagram of a medical networking architecture employing satellite communication is shown in Fig. 1.

Figure 2 illustrates the high level view of the architecture of a medical networking system where several hospitals are connected to the central monitoring or control system using wired or wireless technology. The system comprises of repeaters, gateways and hubs which facilitate connectivity through the network. This architecture can be used to develop an efficient medical network.

Goals of an HDNT

The following list indicates some of the key requirements of an effective medical networking system.

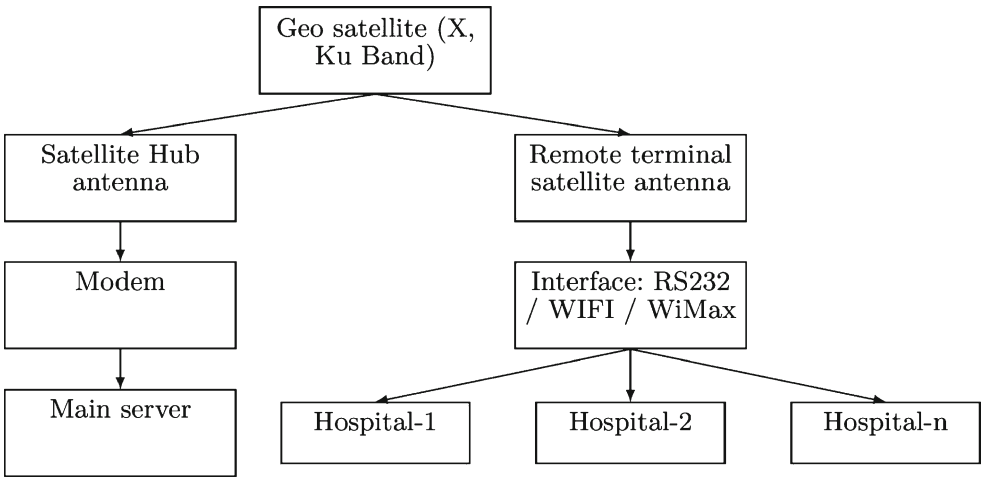

Fig. 1 Overview of medical networking through geostationary satellite

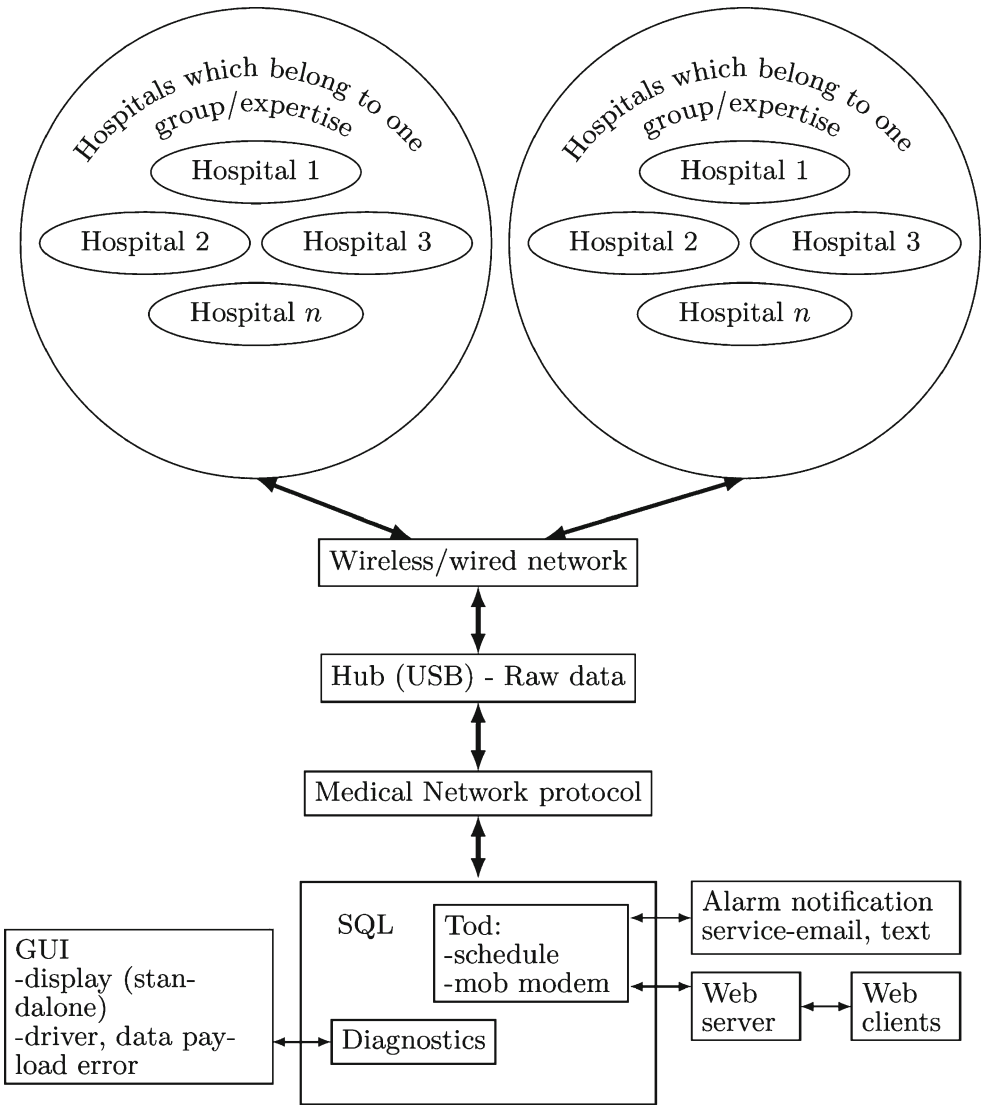

Fig. 2 High level view of the medical network architecture

1. Evidence based management practices should be followed.
2. An international standard that codifies the various interactions between the various modules of the networking system. This should be evolved by a joint group consisting of representatives from various governments, medical personnel, hospital administrators, instrument/software vendors, and networking and communication specialists.
3. This technology should enable physicians to diagnose patients at remote locations and seek a second opinion from other specialists if needed.

Specification refinement

As highlighted in the previous section, there is a notable discrepancy in the health care services available for the rural poor and for the urban people. This discrepancy is going to remain in place for the foreseeable future and cannot be set right easily. However, modern computer and communication technologies together with modern management practices can be leveraged to address this problem. Therefore, there is a need for networking these technologies to address to a large measure, the lack of medical facilities which is a reality in most parts of the developing world. The number of patients, kinds of illnesses to be treated, training, examinations, business and test data, and visitor handling would be estimated and listed. What the hospitals have to do and what equipment and installations they should possess would be set down carefully. Flow diagrams would be set up to show the movement of people physicians, nurses, clerical staff, patients, and others and the type and flow of information and of items like clinical patient records, medicines, X-ray films, food, etc. New technology affecting medical care would be considered. Comparative, economic, and performance analyses would be made of alternative ways of treating patients, location of ambulatory and acute care facilities, layout of the hospital and of modes of operation. The information required and the functions of all the people would be carefully examined.

At the very high end, this system should possess the following properties:

1. An efficient method to extract raw data from the hub.
2. The capability to efficiently handle the Structured Query Language (SQL) queries in the database.
3. An efficient and user friendly Graphical User Interface (GUI) implementation.
4. A medical network protocol which specifies the interconnectivity of various modules in the network.

Implementation

In this section we review some of the techniques used in HDNT implementations. To do this, we discuss the features of telemedicine first. These features are drawn from telemedicine systems which are in existence. These existing systems provide also the basis for Section "Implementation issues in telemedicine", where we discuss implementation issues. After that, we enter into the area of wireless networking. Section "Applications of wireless technology in medical networking" makes the case for wireless networking technology in the area of telemedicine. Next, we outline different wireless technologies before we discuss the types of wireless networks. The last section reviews some applications of wireless technology in the health care sector.

Features of telemedicine

In the last few years, the popularity of mobile phones in virtually every country has increased many folds. Broad band connectivity, radio and television services are now available to middle class citizens in developing countries. Thus, these wired and wireless based technologies can be used to bridge the gap in the provision of medical services to people of all categories. Such a service should have the following minimum features.

1. It should provide basic information about the availability of doctors, nursing homes, tertiary care hospitals, blood banks, diagnostic laboratories and various health care service providers.
2. It should provide secure on-line counseling to assist people to cope with anxiety and stress. The services of trained HIV / AIDS counselors can also be made available through this service.
3. Virtual physical examination of patient through video-conferencing—a process of patient consultation through broad band network to provide medical data—should be evolved. This can involve transmission of video, audio, still or live images between the patient and the physician for use in diagnosis and evolution of a treatment plan. This service can originate from Primary Health Centers (PHC), Community Health Centers (CHS) or designated area hospitals.

4. Once a remote patient monitoring is facilitated, the medical data can be sent to a central control center for interpretation by medical experts. Both results and diagnosis can then be conveyed back to the patient.
5. An online Frequently Asked Questions (FAQ) section on diseases and the best known methods of prevention must be set up. Prevention is better than cure.
6. An online patient database should be maintained by the system, which contains data like date of birth, finger prints (for security purposes) and his or her past medical history. However, security should be provided for database access and usage so that it can be accessed only by authorized personnel. For example the availability of an online database will be useful in monitoring the progress of pregnancy. The health of children as they grow up can also be remotely monitored.
7. The health of people suffering from chronic diseases can be monitored and they can be regularly called to the central hospital for treatment if necessary. This system will also help the authorities in ensuring that events like birth and death are registered.

Thus, this branch of technology, which employs telecommunication and medical electronics as tools, is becoming increasingly popular in many countries as a platform for bringing affordable and good quality medical care to common people. It bridges the rural-urban health care divide. Developing countries are in the process of adopting this system. The system can be designed such that the charges levied on the patient are affordable.

Implementation issues in telemedicine

The vision of such telemedicine based online collaboration systems using multiple information technology tools and covering a wide variety of consumer and management healthcare topics is unfolding very rapidly. The key concepts of integration, transparency, and quality should shape these systems. Very soon, patients, physicians and hospital administrators will be sharing information, expectations, challenges and collaborative solutions using these tools. Some of these systems have already percolated down to the big hospitals. Certain technical and cultural challenges delaying the adoption of telemedicine and Information Technology (IT) in health care services are listed below.

1. Systems integration remains a key underserved area of healthcare IT. In the absence of a worldwide standard, many piecemeal solutions and standalone systems exist. These different solutions have not been designed to communicate with each other. This can make health care system integration a challenging task. Thus, the lack of standardization in the representation of health care data and the lack of interoperability between different products has been a dampener in the adoption of these systems.
2. Generally, integration methods vary from best to worst: point-to-point, Application Programming Interface (API), message-level (HL7) and batch interfaces. This challenge will continue as healthcare providers look to share more information within multi-facility healthcare systems as well as with external providers.
3. There are lots of products for specific tasks but there is still a need for integrated solutions with a standardized information exchange (HL7). In dedicated institutions like, rehabilitation hospitals, there is a need for integrated solutions merging documentation, therapy planning, accounting, etc.
4. Interoperability is going to be the key feature which enables us to move forward. Monolithic products, which were extensively used in the past decade, will not survive because they are too expensive and hard to implement. Healthcare providers will probably go back to a model similar to "best of breed" where they will buy the best ICU tool, emergency department tool, theatre package etc to meet their needs. These tools will have to be designed to communicate with each other.
5. A few companies have developed software for hospitals that are linked to few diagnostic centers. Often this software is designed poorly. For instance, diagnostic centers may send the information to their network hospital, but this information does not reach the respective hospital. Hence, acknowledgement based failsafe medical networking is lacking in most of the existing software used in developed or developing nation's hospitals.
6. When a hospital merges with another hospital, then software integration is a big hurdle, mainly because of freelance implementations of software tools by different vendors in different hospitals.
7. The budget earmarked for adoption of IT networking tools is usually small and hence upgrading the medical networking system is often difficult.
8. Identity management: healthcare providers and healthcare consumers must be assured that that identity information that is collected and collated will be controlled and secured within policy guidelines, like Health Information Portability and

Accountability Act (HIPAA). A lot of effort must be taken to ensure that these safeguards are put into place. This is an area of opportunity to medical networking service providers.

9. In some countries, cultural and legal issues limits technology adoption. In such cases, it is hoped that the passage of time will remove prejudices associated with the adoption of medical networking technology. It is expected that attitudes will change over a period of time and all stake holders in this system will be able to work together for mutual benefit. Thus, it may only be a matter of time before doctors, patients and other health care professionals, located anywhere across the globe, can sit down at a virtual table and talk to each other.

Applications of wireless technology in medical networking

In recent years, the rapid growth of portable electronics and wireless technologies has transformed healthcare policies and it fundamentally shifted the responsibility for healthcare back to the patient, especially for long term chronic diseases. Wireless communication is always a fascination for the medical community through its ability to remove cables, which hinder patient mobility, from health monitoring equipments. Integrating mobile computing, medical sensors, instrumentations and wireless communication technologies with ultra-low power electronics further enable the creation of a new generation of highly mobile, personal healthcare devices which can effectively support e-health and m-health applications by providing extremely flexible vital-sign monitoring systems with powerful mobile communicating systems.

As we know, rural areas might have very little medical supervision available. In situations, where patients are required constant supervision, for example a cardiac condition at mediocre risk level, the patient would find it highly cost-effective as the patient saves on hospital bills if patients could return and bring home a portable hand-held electrocardiogram (ECG) monitor and take regular measurements of his/her ECG signal. The data could then be transferred to the hospital using wireless technology. For example, the popular Bluetooth technology can be used to transfer ECG signals from a small device to a PC anywhere in the household, or through a cell phone, which transmits the data through the internet to the hospital network. Other examples of such usages also include blood glucose measurements and hormonal level control. The following sections briefly highlight the different types of wireless networks, the popular wireless technologies and the current limitations in the usage of these technologies in the medical field.

Wireless Wide Area Network (WWAN)

Wireless Wide Area Networks are wirelessly computer networks that span across very large geographical areas, like cities and countries. WWAN uses standardized mobile telecommunication technologies such as WiMAX (UMTS, GPRS, CDMA2000, GSM, HSDPA or 3G and 4G) to achieve coverage and data transfer capability. Table 2 details the evolution of WWANs and Table 3 provides a comparison of various WWAN types.

Wireless Metropolitan Area Network (WMAN)

WMANs are large networks that usually connect a number of buildings within a city. Technologies like ATM, FDDI, and SMDS are used in WMANs.

Wireless Personal Area Network (WPAN)

Wireless personal area networks are personal networks for interconnecting devices centered on an individual person's workspace. IEEE 802.15 is the 15th working group of the Institute of Electrical and Electronic Engineers (IEEE) 802 standard which specializes in WPAN standards. It includes six task groups numbered from 1

Table 2 Evolution of wireless wide area network

Organi.	1992	1994	1998	2002	2004	2006	2007	2008	2009
3GPP	GSM			UMTS		HSDPA	HSUPA		LTE
3GPP2	CDMA	IS95A	1X		EVDO	EVDO rev A		EVDO rev B	UMB
IEEE	WiFI		802.11 b/g		802.16 d		802.16e WiMAX		802.16m WiMAX
									802.20 MBWA

Table 3 Wireless wide area network comparisons

Standard	Maximum	Average	Medical application
GRPS	114 Kbps	35 Kbps	Text based (browser):
CDMA 1X	153 Kbps	60Kbps	– Text message dispatching
			– Patient database query
EDGE	384 Kbps	115Kbps	Above plus:
			–Basic video;
			–Biometric data (constrained);
			–Reports;
			–Internet.
UMTS	14 Mbps	256 Kbps	All the above plus:
EV-DO	144 Kbps–2.4 Mbps	400 Kbps	– Images;
			– Video (buffert);
HSPA (D/U)	14.4 Mbps	1.0 Mbps	– Remote control.
WiMAX	70 Mbps (coverage up to 50 km)	4.0 Mbps	All the above plus: – Biometric data; – Full motion video;
LTE (Long term evolution)	300 Mbps (coverage up to 100 km)	50 Mbps travelling at 110 km/h (Tested)	– Multimedial; – Remote camera viewing; – Remote control.
802.11g	56 Mbps	14.4 Mbps/	

to 6. There are three possible types of topologies for the WPAN networks as shown in Fig. 3.

Wireless Local Area Network (WLAN)

The wireless LANs connect devices located within a limited area. The latest WLAN technology uses spread spectrum access methods and Orthogonal Frequency-Division Multiplexing (OFDM) modulation for communication. The WLAN can be a peer-to-peer network where the devices directly communicate with each other or it can be a bridge network wherein a wireless bridge allows the connection of devices on a wired Ethernet network to a wireless network.

Wireless Body Area Network (WBAN)

A WBAN is a linking of several intercommunicating sensors that are either worn by the patient or implanted onto the patient for continuous monitoring of vital body signs. These sensors then transmit the collected data to a base station which further transmits the data to a hospital or the clinic.

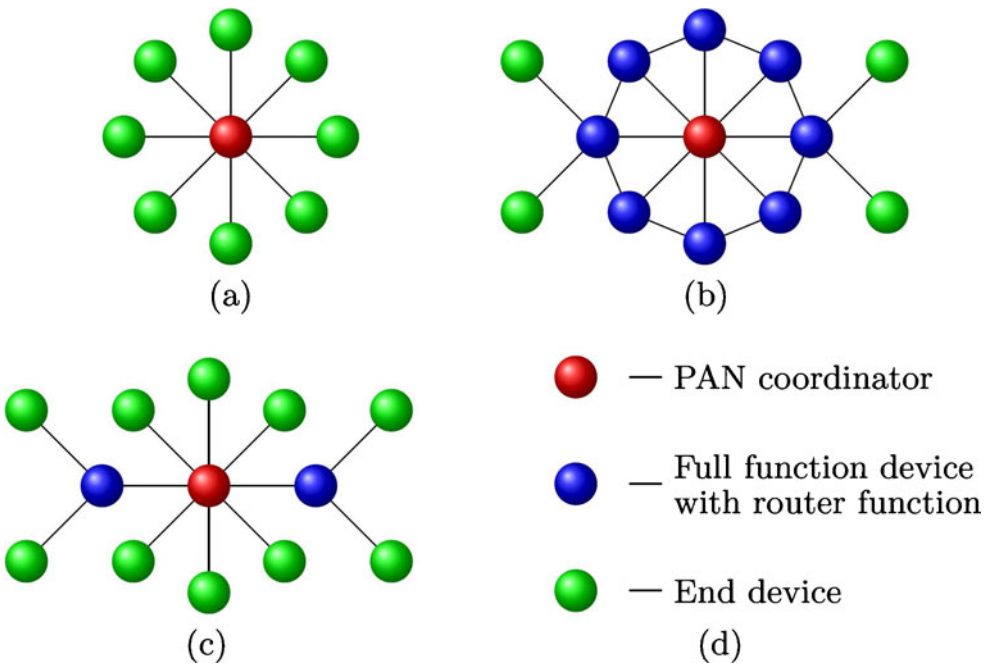

Fig. 3 Network architectures. **a** Star network. **b** Mesh network. **c** Cluster tree network. **d** Legend

Wireless technologies

A few of the popular wireless technologies that find application in the medical field are addressed below.

Bluetooth technology is a WPAN standard. Bluetooth keeps its transmission power to an extremely low, usually in the order of 1 milliwatt, and it is ideal for mobile battery operated devices [30]. Bluetooth devices can automatically detect and communicate with other Bluetooth devices. This is very useful for patients, because they can save the hassle from following necessary procedures before sending their physiological information to their doctors. Bluetooth-capable medical devices can transmit data to other medical devices not within sight of the patient, up to a radius distance of 10 m. Sophisticated protocols ensure that Bluetooth devices experience the least amount of interference from other Bluetooth capable devices while communicating with each other. The protocols control the amount of data that will be sent, the type of communication between the devices and the radio frequency or frequencies used for communication. However, it is not designed for bulk data transfer, Wi-Fi would be a better alternative. Furthermore, Bluetooth can connect several devices together to form larger networks called *piconet*, and several piconets could be formed to connect a wide range of medical devices. In such piconets possible interferences are minimal because the connected devices change their transmission frequencies 1600 times for every second [31]. Power efficiency and security are two conflicting requirements. Therefore, Bluetooth technology does not focus on security. For example, prior to Bluetooth 2.1, encryption is not required and can be turned off at any time. Moreover, the encryption key, defined by the standard, is only good for approximately 23.5 hours; using a single encryption key longer than this time allows simple XOR attacks to retrieve the encryption key.

Wireless and ultra-low power technologies continue to evolve very rapidly. The CSR (Cambridge Silicon Radio) has demonstrated a Ultra-Low Power (ULP) Bluetooth silicon targeted at medical applications. ULP Bluetooth consumes 10 times less power than standard Bluetooth when connected and it achieves a packet data rate which is about 50 times faster than that of standard Bluetooth, implying that the devices consume as little as 1/50th of the power.

Another wireless technological standard, which is cheaper and simpler than Bluetooth, is ZigBee. It is a low-cost, low-power, wireless mesh networking standard based on the IEEE 802.15.4 standard for WPANs. The ZigBee technology has been used in a Home Integrated Health Monitor (HIHM) to transmit several vital signs of the patient, such as ECG, blood pressure, blood glucose, and ear temperature, to a healthcare center [32]. Compared with Bluetooth, ZigBee security, which is based on a 128-bit AES (Advanced Encryption Standard) algorithm, is allways enabled.

Wi-Fi or Wireless Fidelity describes wireless answers that conform to the IEEE 802.11 standards [33]. These standards operate fundamentally on radio waves with a range up to 300 m. The technology actually is an extension of the wired Ethernet with almost the same principles as its wired counterpart, aiming to provide users with identical high speed and reliable connections to the internet. For IEEE 802.11 comes with a choice between no security, Wired Equivalent Privacy (WEP) security and Wi-Fi Protected Access (WPA). For HDNTs no security is not an option. But also the WEP algorithm is not anymore secure [34], therefore WPA is the only sensible choice for HDNTs.

Ultra Wideband (UWB) systems transmit across a much wider frequency range (> 500 MHz) than conventional systems and hence are used for short-range high-bandwidth communications. UWB has many applications in the medical field especially in the areas of imaging, patient motion monitoring, vital signs monitoring etc [35, 36]. UWB systems have an inherited security advantage, because the signal is transmitted within the noise floor. That means, it is extremely difficult to detect the presence of the UWB signal. Apart from this general advantage, the security of UWB signals depends on the particular encryption standard used.

The salient features of the different wireless network modes are shown in Table 4.

With the emergence of wireless communication standards, all newly created wireless medical devices are moving away from proprietary wireless solutions and adopting standard wireless communication technology. In general adopting international wireless communication standards presents the following advantages:

- Greater economy of scale, cost savings, smaller in size and higher reliability through high levels of electronic integration.
- More powerful, robust radio systems with higher communication security which are enabled by low cost microprocessor intelligence.
- Reduced interference in protected medical frequency bands.
- High interoperability between devices.

Applications in the healthcare sector

Wireless technology has been successfully deployed in a wide range of areas within the healthcare sector,

Table 4 Features of different wireless network modes. In the table there are symbols relating to battery types: ◇ = Button Cell, ♡ = AA Batteries and ♣ = Li-Ion

Type	IEEE standard	Data throughput	◇	♡	♣	Protocol stack size	Network range	Network join time
Bluetooth	802.15.1, 802.15.2.1	Mbps 2 Mbps (EDR)	N	Y	Y	250 Kbytes	10 m (typical)	3 s
UWB	802.15.3, 3a	> 20 Mbps	Y	Y	Y	–	10 m	–
ZigBee	802.15.4, 5	< 250 Kbps	Y	Y	Y	28 Kbytes	70 m	30 ms
WBAN	802.15.6	0.01 ≈ 1 Mbps (unconfirmed)	Y	–	–	–	< 2m	–

from supplies and inventory to emergency services. An elaborate discussion of the latest applications of this technology in the healthcare sector can be found in [37]. In the USA, a few ambulance services installed wireless based video systems in the vehicles. These systems capture photo images of the patient and transmit them to hospitals for review ahead of their arrival. Singapore ambulances have also employed wireless devices that communicate with traffic lights, turning red lights to green and vice versa, to free the traffic paths of other vehicles on the road.

In hospitals, mobile workstations utilize wireless technology to allow medical doctors and nurses real time access to patient's electronic monitoring recordings at their bedside. Such workstations are also used in operating theatres where the staff stays in contact with other specialists located in different rooms, or even sometimes in another part of the world.

Healthcare workers, armed with handheld devices in hospitals that have rolled out WLANs, can access information from patient's records, lab results, pharmaceutical information, insurance information, medical resources, work schedules, as well as patient arrival details, furthermore staff has constant access to email within the hospital area. A new area, in which wireless technology is being employed, is wireless health monitoring technology. This technology uses small wearable devices which are strapped onto the patient. These devices transmit physiologic data to a monitor or workstation using wireless technology.

With the adoption of cellular technologies, WWANs have physically removed the range limits and have extended the wide area networks into metropolitan area networks with superb mobility and extreme range of coverage. Both WiMAX and LTE have excellent coverage range (LTE—rural up to 400 sq miles) and support moving vehicles traveling at a speed up to 100 kmph, and are suitable for remote diagnosis, ambulances using audio and video capturing of patient consulting doctor in hospital on-line. This enables quicker and more accurate treatment in shorter time. Ultimately, this will save live and it gives back quality time to the patient by shortening recovery time.

The evolution of e-Health and m-Health systems is driven by both rapid advancement of ultra-low power electronics and low-power wireless communication technologies. These technologies provide very good platforms for the development of wearable electronics, because standardized mass-produced parts can be used, which provide both minimization of weight and size, ubiquitous connectivity, reliability and seamless system integration. A wearable health-monitoring device typically consists of a number of inexpensive, lightweight, miniature and intelligent sensor platforms, each monitoring one of more physiological data, such as electrocardiograms (ECGs), motion sensors or electromyograms (EMGs) etc. These sensors could be located on the body as tiny intelligent units, integrated into user's clothing or implanted under the skin or muscles. In general, these sensors are inter-connected to portable electronic devices using WPAN or WBAN. Global connectivity is feasible using WWAN, where data can be exchanged with external server for long term recording and analysis.

Despite the potential benefits wireless technology has to offer in the healthcare area, it is still not without its problems, namely network performance, battery life of mobile devices, signal reliability and more worrisomely IT security. Wireless technologies are already known to have serious security flaws. Much work is required for wireless standards to meet privacy laws such as HIPAA and the Data Protection Act. These issues must be addressed before wireless technology fully penetrates healthcare.

Discussion

The process of writing this document unearthed a fundamental problem with the planning of modern HDNT. The specification, outlined in Section "Specification refinement", is very short, it is one paragraph and a small number of bullet points. There are several reasons for this shortfall. The most important reason comes from the fact that there is no formal language with which these specifications are formulated. There-

fore, a group of experts, which is composed of decision makes, i.e. administrators, health care professionals and technologists is needed. This group must formalize the semantics of the language which is used to write the specification, i.e. they must define the meaning of the words they use. Only with such strict definitions it is possible to limit the misunderstandings between experts from different fields. The specification itself should be formulated as clearly as possible in an unambiguous way. This can be achieved with formal models.

There is some research going on which applies formal models to health care systems. For example, Goertzen and Stausberg point out that an essential aspect for the utilization of medical data is their quality, thus computer-based medical documentation systems should be reliable and under no circumstances corrupt the data. Therefore, the authors define a grammar for modeling medical documentation systems to increase integrity and completeness of collected data, focusing attention on integrity constraints. An integrity constraint defines requirements with which the involved entities had to comply. Furthermore, it defines possibly implications in case of failure. Their grammar is declared using a schema in extensible markup language-format. The model can be used in computer-aided design and implementation of clinical documentation systems. It achieves both minimizing effort and ensuring data quality. This was tested by an evaluation based on a specification of a registry for HIV-infected patients [38].

Baksi applies a type of formal software verification technique, known as lightweight model checking, to a domain model in healthcare informatics. The Alloy analyzer verification tool is utilized for model checking. The author claims that such verification work is very effective in either uncovering design flaws or in providing guarantees on certain desirable system properties in the earlier phases of the development lifecycle of any critical project [39].

Other research work from Baksi provides formal specification of interactions in typical public health surveillance systems. These systems involve healthcare agencies at local, state and federal levels [40]. The author highlights that the quality of medical care provided is an end result of a well designed choreography of diverse services provided by different healthcare entities. One of the major challenges in this field appears to be explicit formal specification of such interactions. Such formal specification work is the first step leading to both design and verification of important properties of public healthcare systems. Therefore, he modeled two different configurations of public health surveillance systems using π-calculus [41].

Conclusions

In this age, technology has become so all pervasive that we often talk about it as if it were a living creature that will save the day for us in-spite of all our wrong doings. This is not a correct view to adopt. Technology is a mere tool and can be used to heal as well as harm. We need systems thinking to use science and technology in a sensible and beneficial way.

It is not right to think that computer technology can ever treat and cure a patient without human intervention. Hence, it cannot serve as an alternative to the physician. But, the process of diagnosis and treatment can be made affordable and efficient if competent professional doctors, who make use of well designed IT, tools serve the vast majority of people in rural areas who do not otherwise have access to them. To assist this development, an international standard for development of medical networking technology should be evolved. This standard can be tailored / customized according to geographical and cultural needs. Some standardization of diagnostic equipment is also necessary so that seamless transfer of information becomes possible. For example, in USA, Health 2.0[1] is getting a very good chance of becoming the world's leading standard in the area of wireless medical e-health services. It aims to provide breakthroughs in medical networking, hopefully it provides an acceptable international standards, which can be used by users all around the world to make medical advancements and joint collaborations around the world feasible and possible in the near future.

Experts in IT, computer scientists, doctors and healthcare professionals as well as medical software developers should be involved in the analysis, design and implementation of these distributed health information systems and networks. The system administrators in the participating hospitals should be given proper training on the use of these systems. One can only imagine the incredible tedious procedure of having to decipher data which is recorded in a different format to the preferred format that one is familiar with. To overcome this problem, an international standard which allows for the various systems in a medical network to integrate with each other is needed. Many have suggested that influential multi-national IT companies such as Microsoft and Google should come forth to provide the standard, along with other companies. In recent years, Microsoft has developed HealthVault, a common health application platform that can be used for stor-

[1] http://www.health2con.com/

ing and sharing health information between a variety of providers' health services and health devices [42]. Google has come up with Google Health [43] which is a free online personal health information management application. The benefits of such applications are clear as systems designed on the same platform can be easily merged into the medical network, which may even extend the integration at regional and even global levels some day.

In addition to practitioners of allopathic medicine, physicians representing alternative medicine streams also stand to benefit from medical networking. In developing countries, like India, China and Sri Lanka, alternative therapeutic systems have a definite role to play in alleviating sickness—both chronic and acute. As per the report from the World Health Organization, the size of the market for alternative medical systems in India is valued at twelve billion US dollars. As a result of adoption of medical networking technologies, medical tourism will get a big boost and people suffering from chronic diseases, for which allopathic medicine does not have a cure, will benefit. Thus medical networking technologies, if put in place, have the potential to bring healthcare to millions of people in poor countries who are now excluded from modern healthcare. This will go a long way in reducing the pain and suffering of common people at large who still constitute the vast majority of humanity.

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