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Chapter 6

Telemedicine Technology

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INTRODUCTION

THIS CHAPTER FOCUSES on the status of the technology and presents an agenda for future development. Whereas information technology has taken giant strides in developing effective and efficient tools for delivering health services to widely dispersed populations, much remains to be done on the parts of both the technology industry and the health system. Indeed, the ultimate success of telemedicine/telehealth depends on how well the health care system exploits the capabilities of advanced information technology. This technology can extend the reach of medical facilities and resources, promoting efficiency, productivity, accuracy in clinical decision-making, coordination, and integration. At the same time, information technology, for its part, will need to redesign network systems to offer quality of service, bandwidth on demand, and a more effective business model—a model that would charge for network connectivity on the basis of data flow and appropriate speed.

The telemedicine industry as a whole has asserted that the technological requirements for telemedicine systems are already available, albeit at various degrees of efficiency and various levels of cost. Telecommunication links are becoming nearly ubiquitous, but they still do not reach all communities, leaving segments of the population unserved. While off-the-shelf devices provide all the necessary hardware and software for operating telemedicine systems, the development of more advanced technology will enable the creation of telemedicine devices to support more applications.

Still, numerous questions can be raised regarding future trends in technology. The following questions only illustrate the range of issues yet to be resolved. Does the future of wireless and broadband offerings imply that we are on the brink of a revolutionary change in health care delivery? Will the cost of these advancements slow progress, or will competitive pricing resulting from better standards and improved interoperability across products accelerate progress? In view of pending privacy regulations, can the security and privacy arrangements now available meet the needs of the medical profession and patients without compromising quality of service? What are the barriers for the future expansion of telemedicine in the home environment and in the community? Will the expansion of broadband networks, such as Internet2, bring benefits equitably to all segments of society and to all countries?

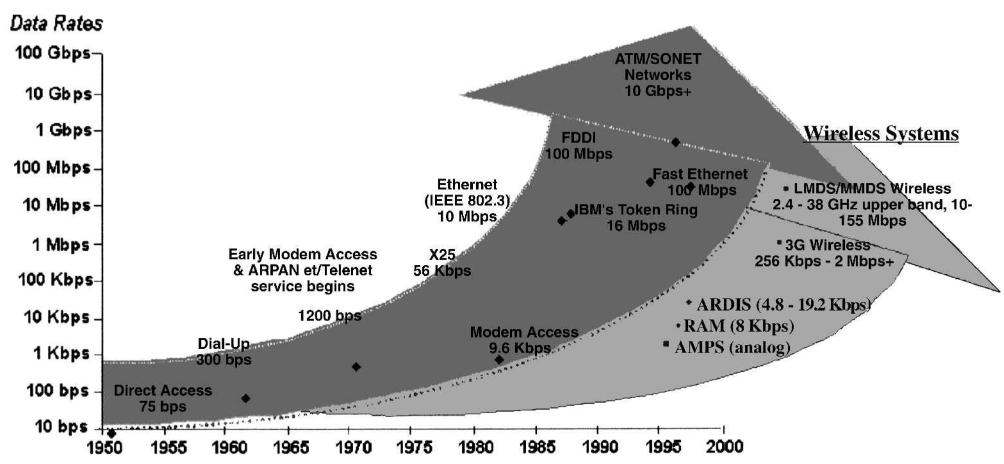
These questions are not necessarily answered in this chapter, and they are beyond its purview. Instead, several equally relevant questions are addressed systematically under the following four topics: technical design, technical applications, interoperability, and security. All these topics are critically important. However, in this report, the discussion will be limited to the first three only. To be sure, security of the data passing through a network or accessible through a network is of vital importance, and risk management must be an integral part of all telemedicine technology.

TECHNICAL DESIGN

Telecommunications support has varied from basic telephone service to broadband Internet, incorporating online diagnostics, remote patient monitoring, and today's virtual touch computer interfaces, referred to as haptics. Figure 1 illustrates the extent of change that has occurred in telecommunications over the past half century. The key item to note is today's multitude of high-speed service offerings that can be used in the design of telemedicine systems.

The asynchronous transfer mode (ATM) is one of the new high-speed offerings available in today's telecommunications market. ATM systems are preferable when high data rate transfers of information are required. When coupled with the resilient synchronous optical network (SONET) configurations, ATM systems offer high-quality and low-delay conditions. Currently, fiberoptic systems are being designed to support data rates as high as 40 gigabytes per second (Gbps) (OC-768) for advanced medical systems.[1–3]

Mobile service for medical applications, such as those encountered in ambulance operations, is critical. As indicated by Casal, et al.,[4] "Mobile communication systems can defined in five groups: cordless, cellular, satellite, paging, and private mobile radio systems. These mobile communication systems will all be included at a common system: the Universal Mobile Telecommunications System, (UTMS)." Prehospital management in emergency care can be essential for patient survival. A portable medical device that transfers patient diagnostic information to physicians at a distant location while in the ambulance has been developed



LEGEND:
- Frequency Band Trends (39-50 MHz, 150 MHz, 400 MHz, 800 MHz, 700 MHz, 2.5 GHz, 5 GHz, 28GHz, 38 GHz)
- Local/Multichannel Multipoint Distribution System (LMDS/MMDS)
- Wireless; Analog/Digital Cable Technology (unlicensed - 2.4–2.5 GHz bands; licensed -24–38 GHz bands with data rates in the 1.5 to 155 Mbps range)
- RAM - Radio Analog Mobile Service
- ARDIS - Advanced Radio Data Information Service
- AMPS - Analog Mobile Paging System

FIG. 1. Evolving telecommunications complexity. (Source: Author Frank Ferrante.)

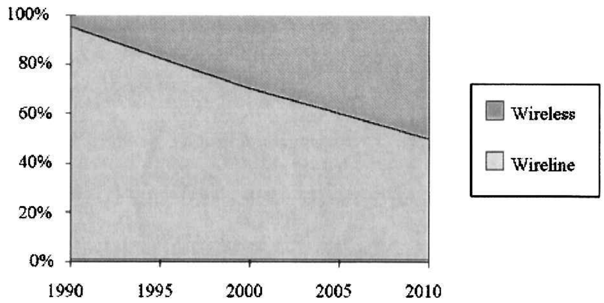


FIG. 2. Growth in wireless vs. wireline. (Source: MITRE Corporation.)

and evaluated.[5] Figure 2 illustrates the recent and predicted future trends in wireless growth.

Wireless systems are defined as first and second generation (1G and 2G or 2.5 G). These network designs offer services for analog voice as well as digital services up to 38 kbps. The next generation of wireless (3G) incorporates broadband, multimedia mobile operations with digital services ranging from 144 kbps across all environments and from 384 kbps pedestrian outdoors up to 2 mbps indoors.[6] As the next generation digital cellular network will have faster and larger transmission capabilities, more complex medical services can be delivered reliably and without degradation of quality.[7]

The concept of intelligent "mobile agents" to support telemedicine applications was described by various authors.[8–10] Essentially these are software agents that can analyze large data sets and retrieve specific information relevant for clinical decision making.

The range and complexity of telecommunications technology requirements vary with specific medical or health applications. However, generically defined digital medical devices impose the telecommunications performance requirements. Table 1 illustrates a sampling of several of the more common digital medical devices used in telemedicine. Figure 3 illustrates the image sizing determination for the devices listed in Table 1. Except for the last few items contained in the table (starting with ultrasounds and running through full-motion video), the majority of vital sign medical devices require relatively low data transmission rates. Capabilities currently offered by these systems, even 1G and 2G wireless and basic telephone connections, would support the transfer of information provided error free or as "error detecting and correcting" processes.

Tradeoff must be considered when choosing a telecommunications system for high data intensive services, as illustrated in Figure 4. This example assumes digital radiography requiring 2048×2048 pixels for quality and 12 bits per pixel. In this example, it would take almost 30 minutes to compete the transfer of a single image when using a modem and a speed of 28.8 kbps. This is clearly unacceptable given that several views of a single patient must be transmitted in a single episode. However, the newest telecommunications offerings reduce the time per view to less than a second per view (at OC-768).

In the following section, a few demonstration projects from several countries are briefly described to illustrate the range of applications.

TABLE 1. DATA RATES OF TYPICAL DEVICES USED IN TELEMEDICINE

Digital device	*Data rate required*
Digital Blood Pressure Monitor (sphygmomanometer)	<10 kilobits of data per second (kbps) (required transmission rates)
Digital thermometer	<10 kb of data (required transmission rates)
Digital audio stethoscope and integrated electrocardiogram	<10 kb of data (required transmission rates)
Ultrasound, Angiogram	256 kilobytes (KB) (image size)
Magnetic resonance image	384 KB (image size)
Scanned x-ray	1.8 megabytes (MB) (image size)
Digital radiography	6 MB (image size)
Mammogram	24 MB (image size)
Compressed and full motion video (e.g., nasopharyngoscope, ophthalmoscope, proctoscope, episcope, ENT scope)	384 kbps to 1.544 Mb/s (speed)

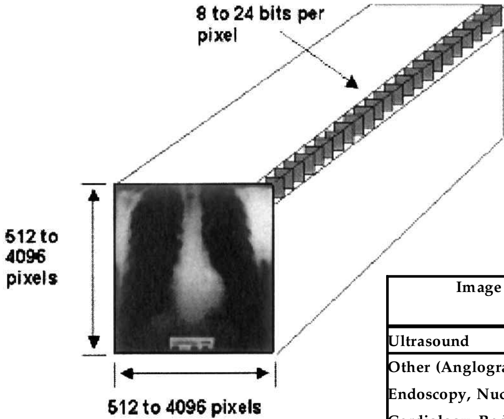


Image Type	Image Resolution		Image Size
	Spatial	Contrast	
Ultrasound	512x512	x8	256 Kbytes
Other (Anglography, Endoscopy, Nuclear Med., Cardiology, Radiology)	512x512	x8	256 Kbytes
Computed Tomography	512x512	x12	384 Kbytes
Magnetic Resonnance Imaging	512x512	x12	384 Kbytes
Digitized (Scanned) X-ray	1024x1250	x12	1.8 Kbytes
Digital Radiography	1024x1024	x8	1 Kbytes
	2048x2048	x12	6 Kbytes
Mammography	4096x4096	x12	24 Kbytes

FIG. 3. Teleradiology imaging applications. (Source: Author Frank Ferrante.)

The first is a collaborative model system developed by Mitre Corporation (McLean, VA). It used two ATM high-speed switching units to support concurrent transfer of voice, data, and video between several medical facilities. Images from this system are shown in Figure 5 (Mitre Corporation, 1995). This system demonstrated a practical application of ATM systems using real-time microscopic image transfers, concurrent with magnetic resonance imaging (MRI) images, live video and audio, and collaborative capabilities between research facilities.

A novel emergency telemedicine system based on wireless communications, AMBULANCE[5] demonstrated a successful wireless telemedicine system at four different sites in Europe. The goal of the project was to transmit medical information from an emergency ambulance to distant medical facilities for consultation. The project reported less than 10% interruptions in communication, and only 5% of wireless connections were actually lost.

A digital wireless system, referred to as the global system for mobile (GSM) communica-

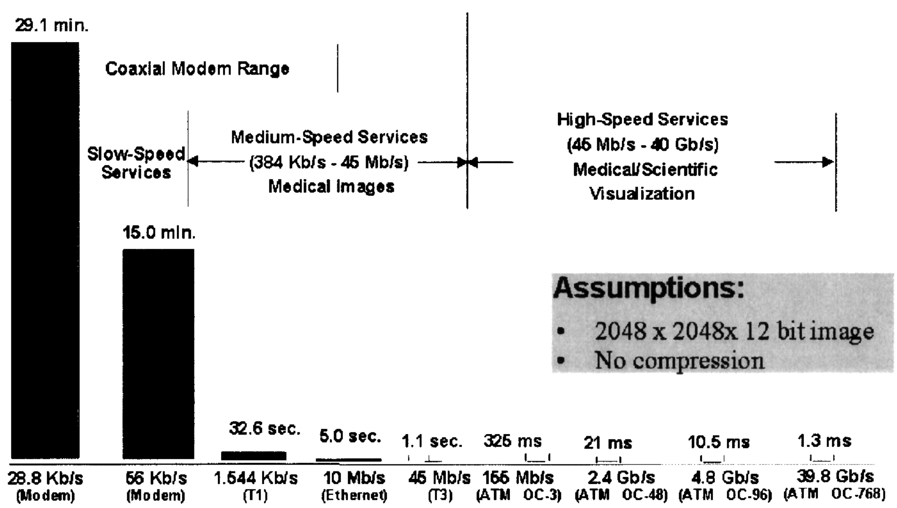


FIG. 4. Image transmission times.

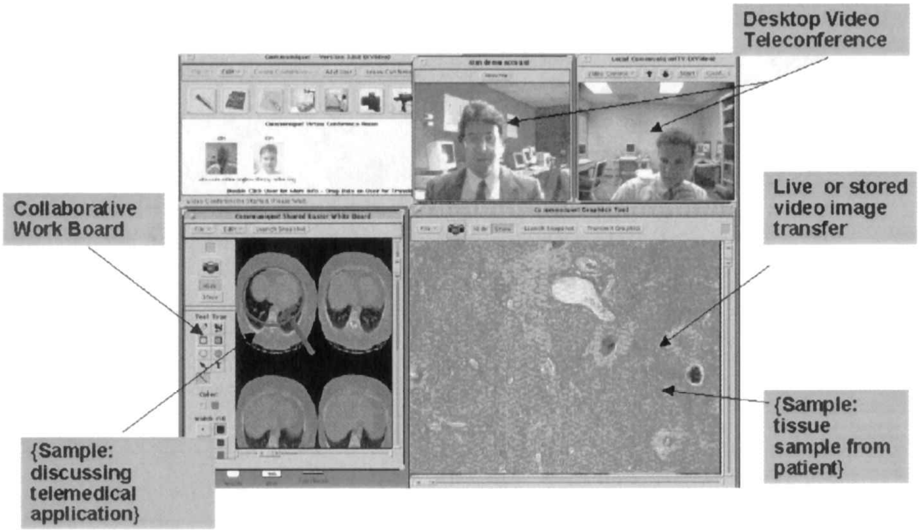


FIG. 5. Asychronous transfer mode (ATM) collaborative computing in a telemedicine application. (Source: MITRE Corporation, 1995).

tions, the system used for cell phones proved more than capable of meeting the minimum thresholds of medical data transfer rates. Generally, GSM was employed in cases where the emergency site was on average 40 minutes away from a medical facility. In some instances, myocardial infarctions (MIs) were treated with thrombolytic therapy before the patient was transported to the hospital.

In a "Home Telecare System Using Cable Television Plants: An Experimental Field Trial," Lee[12] describes an ongoing demonstration in Taiwan using hybrid fiber coaxial cable (HFC). Integrated service digital network (ISDN) and ATM configurations as well as basic "twisted pair" telephone service were also considered before settling on HFC as the most cost-effective solution. These services included a three-channel electrocardiogram (ECG), blood pressure, and live video and audio service. ECG transmissions were successfully completed.

INTEROPERABILITY

To date, much of the engineering work in telemedicine has consisted of integrating off-the-shelf components to enable various clinical applications. As a result, these systems can be costly and inflexible. While they perform well in terms of their intended functions, adding new features can be costly and time consuming. Moreover, the "closed" designs of these systems means that the telemedicine stations from one vendor may not be able to communicate with those produced by another vendor.

To address these shortcomings, the telemedicine community needs a three-level approach to telemedicine system interoperability. First, stations developed by independent vendors must be able to interact with each other. Second, medical devices and other "peripherals" connected to one vendor's station must be able to interact with stations created by other vendors. Finally, it should be possible to create individual stations in plug-and-play fashion from components developed by multiple vendors. The first level of interoperability can be implemented with only limited change in existing systems, and the second level does not necessarily require the first. Reaching consensus on the third level will require substantial effort but will be rewarded by equally substantial benefits.

At the first level, a station wanting to interact with other stations advertises its existence in a "registry server"—a public resource that contains both address and attribute data describing various telemedicine stations. The station wanting to find a specific station or a certain type of station queries the registry server and is provided with the address of at least one station that fits the query. Using this address, the station contacts the desired station and inquires about the specific medical devices and other resources installed at the host station. Subsequently, the requesting station reserves specific resources and a proposed quality of service and security parameters to be used during the session. If the host station responds positively, the two stations negotiate with the network to establish the quality of service requirement for the session. Once a session is established, the requesting station interacts with the resources that it has "leased" from the host station as if these resources were local at the requesting station. This is the simplest form of interoperability.

To address the second level requires standardizing the interfaces of devices (e.g., medical instruments or patient record cards) that attach to a station. It also requires that the station be able to monitor when devices have been added or removed, and that other components in the station be able to explore and employ devices dynamically attached in this way. One approach to achieving this would be through the use of a "station registry," which maintains descriptions of all the components that make up the station and is able to alert other station components when a given kind of device has been added. If implemented, this level of interoperability makes it possible for end users to create, in plug-and-play fashion, a range of stations to meet a diverse collection of healthcare delivery needs.

The third level requires the creation of systems that are based on shared, distributed resources. For instance, in the future, this might allow medical peripherals and software to be added to a home's existing computing and communications infrastructure to create a home-based telemedicine station.

RECOMMENDATIONS

The agenda for technology development and deployment would necessarily require closer coordination between industry and the health care sector to design more efficient systems and to exploit the capabilities of these systems more fully to deliver remote health care. The following areas require special attention.

Middleware

Hardware manufacturers and software developers typically try to design and develop proprietary systems. Successful proprietary systems are highly rewarded in the marketplace because they limit competition and assure a certain market share with a lock on their product. (One distressing feature about standards is the fact that there are so many to choose from.) The most pressing engineering need in telemedicine is middleware, an area that falls between software engineers and network engineers.

Interoperability

Whereas interoperability can be achieved at different levels through standardization and integration, some of these levels may not be achievable in the foreseeable future. Indeed, in the short term, we are not likely to develop fully interoperable telemedicine stations that can interact with each other and make use of each other's devices. Hence, the most pressing need is for middleware (the area between software and network engineering), in both forms hardware and software. Middleware will be the glue that renders incompatible standards interoperable, and it is feasible in the short term.

Perhaps the first step in reaching interoperability is to streamline or create interoperability between seemingly divergent policies. Often, policies and regulations drive the development of technology. This is especially true for technologies that will be required to implement the security and privacy regulations mandated by the Health Insurance Portability and Accountability Act of 1996 (HIPAA). Once final agreement is reached on a set of compatible HIPAA-mandated policies, hardware and software development can proceed and implement these policies. The opportunity for compatibility between various policies and regulations should not be missed.

Portability will also need to be assured through portable medical devices and smart cards. These portable devices must include all systems, including biosignal monitoring, image acquisition and display devices and nomadic computing.[11]

MEMS

Micro Engineer Machine Systems (MEMS) and other forms of nano-technology represent new opportunities for telemedicine. MEMS can take different forms, including MEMS robots in noninvasive arthroscopic surgery, MEMS-encapsulated cameras that can be swallowed to provide detailed images of the digestive tract, and so on. Similarly, wearable wireless sensors can monitor physiological functions in various environments. Work must continue in this highly promising area.

Human/machine interface

Whereas output requires proper displays, input requires better sensors. The quest for designing optimal machine/human interface is ongoing. It is prompted by the need for better, more natural displays and for better, less invasive sensors. Indeed, the optimal design of a human/machine interface may be doubly important in telemedicine because every telemedicine episode requires two interfaces, one at the patient or remote provider site and the other on the consultant side. The interface renders certain pieces of equipment usable or not usable, and the use of telemedicine desirable or not desirable.

The ultimate and most natural human/machine interface is natural language. The development of a human-to-machine natural language would have an especially substantial impact on the home telemedicine market. Research in this area must be a high priority.

Knowledge robots

The development of intelligent medical robots, called "know-bots," will be critical for the future of telemedicine. Each person would have his/her own intelligent avatar that lives on the Internet as well as the person's electronic health record. The know-bot would understand spoken natural language and could respond to inquiries for medical information on the Internet relevant to a person's medical history. The know-bot could also act as a monitor to alert its owner about unhealthy trends in the health record and for inconsistencies in the record.

The medical know-bots could decrease medical errors or enhance quality of care. They could provide relevant and timely information for health promotion, disease prevention, and clinical decision making. Unfortunately, this technology is not likely to appear in resource-constrained countries or isolated rural areas. The challenge here is economic and not technological.

Data integrity and validation

Security systems must be built into every telemedicine network. These systems must be able to ascertain a "real" image and derived images and to authenticate the source.

Technology transfer

The information technology that supports telemedicine is being developed in a variety of settings for a variety of purposes and applications. Much of this developmental work is occurring outside the health care field. Technology transfer, or borrowing, must become a high priority. The network infrastructure for future telemedicine is likely to be public and not private. Hence, it is important to encourage the use of digital video, H. 323 (or Internet Protocols), Health Level 7 (HL7), as well as an open source for software. The ultimate goal is to guarantee end-to-end connectivity. Technology transfer between resource rich and resource poor countries must be a high priority.

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