

Telemedicine: Health Care at a Distance

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Attention to telemedicine today is fueled by the desire to provide health care to people with limited access; reduce the cost of health care to those who now have access; and provide quality care to deployed military personnel, especially for the treatment of battle casualties. These interests, combined with advances in computer technology and the development of a global communications infrastructure, portend a significant role for telemedicine. This article describes the technologies integral to telemedicine as well as telemedicine initiatives in which the Laboratory is active.

INTRODUCTION

Telemedicine, literally medicine at a distance, is the delivery of health care over long distances using medical knowledge combined with communications and computer technology. Aspects of this field include clinical medicine (diagnosis, treatment, and documentation) and academic medicine (research, education, and training). Selected features of telemedicine have been in place since the advent of the telephone and have been effective in limited and unique situations, typically aiding the delivery of health care in remote locations and in circumscribed support of education and training. Costs, reimbursement policies, liability issues, insufficient standards, and technological limitations have constrained its further development and utilization. Only recently have advances in information technology and the potential for global communications positioned telemedicine as a serious force in clinical and academic medicine.

TELECOMMUNICATIONS

Transmission rates for telemedicine are driven primarily by the desire for extremely-high-quality images

for pathology and radiology, the need for full-motion video, and the ability to carry out sophisticated processing at nodes with desktop computers. The capabilities of desktop and client-server digital processors continue to expand dramatically as costs decrease. The advent of the Pentium and Power PC microprocessor chips as well as faster, cheaper random access and magnetic memories have increased processor operating speed to 100 Mlps. Their multimedia applications, which combine sound, still images, text, and full-motion video, heighten demand for more transmission bandwidth.

Affordable wideband global telecommunications are becoming a reality owing to the proliferation of optical fiber transmission and wireless systems; advances in high-speed hardware including digital electronic, electro-optical, and optical integrated circuits; international agreements on standards; improved compression techniques; and the development of intelligent software. Relatively inexpensive optical fiber cable is quickly replacing copper as the primary transmission medium between fixed sites. Optical fiber cable transmission systems offer many advantages:

- Higher transmission bandwidths
- Low impedance to light waves, allowing for longer repeater distances
- No cross talk between fibers
- Lower transmission errors, mass and volume, cost, and power requirements
- Improved security (tapping is more difficult)
- More flexibility for easier installation
- Decreased sensitivity to environmental effects (e.g., lightning, solar storms)

Two types of optical fiber cables—multimode and single-mode—are in use. Multimode cable is cheaper to install but is limited to transmission rates of less than about 155 Mbps and distances between nodes of less than 2 km. Consequently, it is primarily used for local-area networks. Single-mode optical fiber cable, although more expensive because of the associated electronics, can transmit over longer distances between nodes, up to 50 km, and at higher rates, approaching 400 Gbps in laboratory tests. Optical amplifiers being developed will increase this distance significantly.

Wide-area networks link geographically distributed communication nodes and include dial-up analog and digital transmission over the Public Switched Telephone Network (PSTN) and digital transmission over shared or dedicated leased lines. Plain Old Telephone Service (POTS) can transmit between 9.6 and 28.8 kbps over existing analog networks. Digital transmission using the Integrated Services Digital Network (ISDN), which is being installed by telephone companies, has a standard interface consisting of a basic rate with dual 64-kbps voice/data channels and a T1 transmission primary rate of 1.544 Mbps. This rate is insufficient for the transfer of high-quality images, since, for instance, VHS-quality video requires about 1.2 Mbps and high-definition television up to 50 Mbps. The Switched Multimegabit Data Service (SMDS), which now operates at rates up to the T3 line rate of 44.736 Mbps, is available in some metropolitan areas and is expected to be accessible regionally in the near future.

The acceptance of telemedicine for comprehensive care will depend on the ability to exchange multimedia data globally through a wide range of data rates. To accomplish this exchange, the Broadband ISDN (B-ISDN) is being developed. This is being implemented as a global network supporting different kinds of applications and users. It has the 64-kbps capabilities of ISDN, but much higher bandwidths are also available, typically up to many gigabits per second. In addition, it supports point-to-point and point-to-multipoint connections and offers permanent and on-demand services. As a result, the B-ISDN should satisfy the requirements of most telecommunications applications, including telemedicine.

Key to the success of the B-ISDN are two technologies: (1) the asynchronous transfer mode (ATM) transmission and switching and (2) the synchronous optical network (SONET) transport. The former is capable of high bandwidth and low switching delays; can support voice, video, and data in the same public network; functions at the data link layer of the network model; transfers data between entities; and can detect errors. It does so by combining the advantages of both circuit-switching and packet-switching techniques. The ATM does not establish channels, as in synchronous transfer modes, but instead transmits cells with fixed lengths of 53 bytes. A header in each cell enables it to resemble conventional packet switching so that time-variant bit rates can be tailored to the users' needs. Relatively short and fixed-length cells at high data rates produce transfer delays that are small enough to enable ATM to support a wide range of users. Cells can be transported asynchronously or synchronously. Either way, the user receives data at variable intervals, resulting in asynchronous transmission.

The SONET is the U.S. equivalent of the European synchronous digital hierarchy (SDH) and is a transport technology standard that defines the electrical and mechanical requirements of the communications media and interface hardware. It functions at the physical layer of the network model, establishes and terminates connection to the communications medium, shares resources among multiple users, controls the data flow and resolves contention, and converts between the digital data used in the network equipment and the signals transmitted over the communications channel. Transmission line rates for SONET/SDH range from optical carrier 1 (OC-1) at 51.840 Mbps with 2016 channels of 64 kbps each to OC-192 at 9953.280 Mbps with 129,024 channels of 64 kbps each. International agreement on a SONET/SDH standard means that different vendors can develop compatible hardware so that B-ISDNs can be established more easily and quickly. SONET/SDH and ATM together enable the B-ISDN to provide extremely-high and variable bandwidth on demand for transmission of multimedia data for all users.

Wireless communication is important for remote, fixed sites and transportable and portable terminals. The use of cellular circuits will continue to grow exponentially but will ultimately be limited by the bandwidth available. Cellular technology using terrestrial networks is available in the developed nations. Communications satellites provide service to multiple users in a given region and to individual users in remote locations. Satellite service is especially attractive in less developed areas lacking a terrestrial telecommunications infrastructure and for mobile military forces. Nearly 200 communications satellites are already in synchronous orbit; about 1000 more are expected to be

launched. Depending on the size of the receiving antenna, satellite transmission can reach 10 Mbps. Terminals with very small apertures (less than 0.5 m) work with existing satellite constellations. Several additional satellite/personal-communications systems are under development to provide global communications with handheld units. These systems include the ICO Global Communication System's Inmarsat-P system, Loral and Qualcomm's GLOBALSTAR, Microsoft's Teledesic, Motorola's Iridium, and TRW's Odyssey. Selected service is expected as early as 1997.

Future telecommunications systems will probably never provide sufficient transmission rates for some users. However, those who can effectively use lower bandwidths will have a competitive edge. Consequently, data compression techniques will continue to be important in reducing transmission delays and providing a cost advantage. Data compression factors of 10 to 20 are often achievable today. In some cases, especially when background information is not changing, even higher compression factors are possible. This remains a fruitful area of research.

TELEMEDICINE AT THE APPLIED PHYSICS LABORATORY

The Laboratory now leases over 30 separate lines of various bandwidths to satisfy its broad telecommunications requirements. Today, The Johns Hopkins University and Health System are planning to install a SONET/ATM network to connect their research, educational, and clinical facilities in the Maryland and Washington areas, including APL. This network resulted from a strategic study group chaired by the author that addressed the telecommunications needs of the University and made recommendations for developing a fully integrated and interoperable system. It is to be an OC-12 network with a line rate of 622.08 Mbps, which is equivalent to 2016 channels at 64 kbps. This capability will enable the Laboratory to carry out wide-band communications to support its research in all areas, including telemedicine. Bandwidths of this order of magnitude are necessary for teleradiology and telepathology studies and research.

A telemedicine experiment of current interest involves a system developed by the Laboratory under its Independent Research and Development Program to support the Lincoln Carrier Battle Group, which is, as of this writing, on-station in a high threat area. The system consists of 12 inexpensive workstations costing less than \$3000 each; workstations have been deployed on the USS *Abraham Lincoln* (2), on selected ships in the Lincoln Carrier Battle Group (3), at the Balboa Naval Hospital in San Diego (1), at the Naval

Aerospace and Operational Medical Institute in Pensacola (2), at the Naval Air Station in Alameda (1), at Destroyer Squadron-33 in San Diego (1), and at APL (2).

The system uses standard land-line and cellular telephone hookups and COMSAT Corporation's Inmarsat communications satellites at a nominal data rate of about 14.4 kbps. COMSAT Corporation has graciously donated up to 2 h per day for this experiment to help support the health and welfare of military personnel on-station. The purposes of deploying this limited system are to make consultation available to physicians and corpsmen in the field and to determine the requirements for a more capable operational system. Preliminary experiments in which physicians at Hopkins and elsewhere have provided diagnostic, treatment, and surgical consultation (including real-time laparoscopic surgery) have been judged to be quite successful. The system is also used in special circumstances for televisiting between naval personnel and their families.

An additional telemedicine initiative in which APL is engaged is support of JHPIEGO, another Hopkins Division. Its purpose is to carry out worldwide training that addresses women's health issues. The Laboratory's role is to help develop computerized training modules for distribution through the Internet to a widely dispersed corps of paraprofessionals for further distribution to train women in remote areas.

SUMMARY

The potential of telemedicine, anticipated for many years, is more of a reality today because of government and industry interest in developing a global telecommunications infrastructure. Congress is now considering the Telecommunication Reform Act, which will change our communications laws, some enacted over 50 years ago. The aims of the act are to increase competition in all telecommunications markets and to provide for an orderly transition from regulated to deregulated and competitive telecommunications markets. In addition, Vice President Gore has made the information highway a priority of the Clinton administration. However, issues relating to reimbursement, liability, privacy, and documentation remain unanswered. Also important is the acceptance of telemedicine by health care providers, patients, and the insurance industry.

The telecommunications industry, recognizing that the technology and standards are finally here, is making significant investments to bring electronic information to anyone anywhere in the world at any time. The use of telemedicine to improve access, to improve quality, and to reduce costs is at hand.

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