Wide Area Networks for Teleradiology

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Teleradiology networks transmit digital radiographic images from one location to another. These networks are wide area networks. Teleradiology networks are used for diagnostic purposes and preview tasks. Wide area networks for teleradiology use public service switching. The use of fiber optics networks provide reduced costs and increased flexibility. An example is presented that compares the cost of teleradiology networks.

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TELERADIOLOGY networks transmit digital radiographic images and consultative text from one radiographic service location to another. These digital networks connect sites for purposes of interpreting patient's images. Connected sites may be located in remote areas as well as health facilities having no full time radiology coverage. There are two types of teleradiology networks: high-resolution (diagnostic) and low-resolution (preview). High-resolution teleradiology networks may be used to integrate multihospital/clinic health care consortiums (HMOs), for emergency service coverage or to provide subspecialty interpretation. Low-resolution teleradiology networks may be used to preview acquired images at home on evenings or weekends to provide prompt advice to physicians in emergency rooms, intensive care units, or elsewhere in the hospital. The various digital image data array sizes to be transmitted are identified in Table 1.

A teleradiology system is a computer communications^{1,2} wide area network³ (WAN). A teleradiology WAN extends over large distances and connects computers together with the capability of transmitting any of the digital image data identified in Table 1.

Sites wishing to join an existing teleradiology system are either already paying for radiology coverage services (in varying degrees) or want to acquire increased radiology coverage. If the existing radiology coverage is by contract services, then some of these funds can be shifted to support the teleradiology system. The hardware cost for a high-resolution system per site is

\$239,000 to \$377,000 (Tables 2 and 3). These costs will decrease as the number of purchased teleradiology systems grow. The communication costs will add additional expense of 12% to 30% per year depending on the type of digital service chosen. WAN communication costs were once the most expensive item in any computer communications network. However, these costs are decreasing as the extensive bandwidth of fiber optics networks becomes available. This article examines the issues and cost of digital communications for WAN teleradiology networks.

TYPES OF WIDE AREA NETWORKS FOR TELERADIOLOGY

There are three types of public digital service computer communication networks available. They are circuit switching, message switching, and packet switching.

Circuit Switching

In circuit switching,⁴ (Fig 1) a complete route of connected links from the source host computer to the receiving host computer is established before the initiation of transmission. These connected links remain "intact" and dedicated to this transmission until released by both the source and the receiver. In the same manner as the telephone network for voice communication, the route is established by a special signaling message that finds its way through the network from the source to receiver, seizing channel links in the route as it proceeds. Once the route is completed, a return signal is sent to the source to initiate transmission of the image data. During transmission, the source and receiver have a circuit connecting them during the entire transmission. When transmission is completed, signaling on the

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Table 1. Digital Image Array Sizes

Modality	Megabytes Per Image	Average No. of Images Per Exam	Average No. of Megabytes Per Exam
CT	0.5	30	15
512 × 512 × 12 bits			
MRI	0.13	50	6.5
256 × 256 × 12 bits			
DSA	1.0	20	20
1K × 1K × 8 bits			
Digital fluorography	1.0	15	15
1K × 1K × 8 bits			
Ultrasound	0.25	36	9
512 × 512 × 6 bits			
Nuclear medicine	0.016	26	0.416
128 × 128 × 8 bits			
Computed radiography	8.0	4	32
2K × 2K × 10 bits			
Digitized film	8.0	4	32
2K × 2K × 12 bits			
Digitized film	32	4	128
4K × 4K × 12 bits			

network disconnects the communication links used.

In Fig 1, the host computer at Site A is transmitting image data to Site C. The WAN circuit switching network has selected the path shown for transmission. This path will be released by special signals when both the transmitting host and receiving host notify the WAN that transmission has been completed.

The simplest circuit switch is one which has N-inputs and M-outputs. This type of circuit switch is called a space division switch.⁵ At the intersection of each input and output is an element called a crosspoint (called crossbars in the telephone network). Advances in very large scale integrated (VLSI) technology permit from 256 to 1,024 crosspoints in a single chip. The individual crosspoints are capable of passing

digital signals with data rates from 100 M bits per second to over 1 G bits per second. Switching times are on the order of a few nanoseconds.

A second type of circuit switch is a time division switch.⁶ Bytes of data from N-input channels are time multiplexed together, written sequentially into a semiconductor memory, and then by computer control are read out and demultiplexed to the correct output channel. VLSI technology permits a single silicon chip to provide 1,024 channel time division switches, where the individual channels are operating at 56 k bits per second or 64 k bits per seconds.

Most digital switching systems use a combination of space and time division switching. These systems provide digital services of 64 k bits per second (or 56 k bits per second), 1.5 M bits per

Table 2. Hardware and Maintenance Costs for Each Site (A, B, and C)

Equipment Item	Estimated Costs
Laser film digitizer	\$72,000
Interactive gray scale workstation	38,000
Host computer system	45,000
Optical disc archiving	23,000
Network access controller	18,000
Maintenance costs (10% per year of hardware costs)	21,740
Total	\$217,740

Table 3. Hardware and Maintenance Costs for Academic Radiology Department

Equipment Item	Estimated Costs
Laser film digitizer	\$72,000
Laser film printer	78,000
Host computer system	55,000
Optical disc archiving	50,000
Interactive gray scale workstation	70,000
Network access controller	18,000
Maintenance costs (10% per year of hardware costs)	34,300
Total	\$377,300

Fig 1. Circuit switching path from Site A to Site C. (---, available paths; ○, circuit switch; →, circuit path selected).

second (DS-1), and 45 M bits per second (DS-3). Time and space switching will permit digital services in the G bits per second range needed by fiber optics links.

Message Switching

One characteristic of computer-to-computer communication traffic is its "impulse" characteristic. Communications will consist of bursts of high-data rates followed by almost no data transmission. This implies that the average use of such communication paths will be low. In message switching (also called "store and forward" switching),⁷ there is no complete path established before starting transmission. Rather, the sending host computer will transmit a message to a switching center where it will be stored in a buffer. The stored message is kept in this buffer until the line to another switching center is available. When this line becomes available, the stored message is forwarded. This process is continued until the data arrives at the receiving host computer.

The advantage of this technique is that the link use is high, for one link may be involved in sending data to many host computers. The disadvantage is that long messages, such as digital images, require large storage buffers.

Furthermore, even if a link becomes available, a switching computer will not begin to transmit a message until it has been completely received.

Packet Switching

A packet switching network⁸⁻¹⁰ subdivides messages into small sizes, called packets, typically 1,024 bits. The message is transmitted packet-by-packet. Packet switching is a store-and-forward system where each packet is stored in buffers at the nodes on the network and then forwarded. Packets may follow different routes on the network and may arrive at the receiving host computer out of the sequence in which they were transmitted. For this reason, all packets are numbered so that they can be reassembled back into the original message.

Packet switching for messages of varying length provide the advantage of dynamic and fair allocation of the WAN's available bandwidth. The end-to-end transmission delay is smaller than that of message switching due to the division of the message into many smaller size packets and their transmission over multiple path lengths. Packet switching requires smaller storage at each node on the network than does message switching. Each packet includes information bits as well as additional bits

called overhead information. The overhead bits are used to identify the destination of the packet, the source of the packet, user identification (for charging purposes), synchronization bits, and numbering bits (so as to properly reassemble the packets at the receiving host computer). Packet switching has the disadvantages that: packet switching requires the transmission of both information bits and overhead bits; and the packet switching hardware must "packetize" the messages, add overhead, de-packetize and reassemble the message. However, due to the pipelining effect of packet transmission (multiple packets could be transmitted over multiple links), it is possible that packet switching will transmit a message in less time than that of message switching.

A local area network (LAN)¹¹ is a packet switching network. The network consists of a single transmission medium that is shared by all nodes (multiaccess-broadcast). Network access is controlled by standard protocols, called media access control protocol. Packets are sent on the shared access medium. Any transmitting node's packet is heard by all other nodes (broadcasting). The packet switching function is accomplished by the sharing of a broadcast medium multiaccess protocol in which each receiving node accepts packets addressed to it. Signaling data rates on LAN's range from 1 to 100 M bits per second.

Integrated Services Digital Network (ISDN)

The telephone network was developed as an analog transmission system. Replacement of the analog system by a digital system was broadened to include voice, data, and images. The advent of digital signal processing technology and computer systems, digital switches, and digital transmission is gradually replacing electromechanical switches and the analog facilities between them. Analog voice grade lines have been replaced with pulse code modulated (PCM) digital data voice grade channels, operating at data rates of 64 k bits/second. A channel bank is used to convert 24 analog voice channels using analog-to-digital conversion so as to provide a T1 service of 1.544 M bits/second. A channel bank is required at each end of the communication link to convert the analog signal to digital data

and digital signals to analog signals. Digital switches are being incorporated into the toll central offices, the local central offices, and digital signaling between these exchanges. An ISDN standard was established by the Consultative Committee for International Telephone and Telegraph (CCITT) for the functional standards of ISDN. To improve signaling speeds for the set-up and take-down communication links, a separate channel was established, called the common channel signaling network (Fig 2). As the evolution towards ISDN¹² continues, local loops (which connects the local switching exchange to office/home) are being converted to digital links capable of transmitting two 64 k bit/second channels (a B channel signals at 64 k bit/second) and a D channel (a D channel signals at 16 k bits/second) for signaling rates. Thus the basic rate access on the local loops is 2 B + D, or 128 k bits/second plus 16 k bits/second for signaling. With ISDN, digital communications at 128 k bits/second (plus D channel control signaling of 16 k bits/second) is made available to homes and offices similar to the dial-up telephone capabilities. The primary rate access for digital links between exchanges is 1.544 M bits/second (23 B + D channels).

The ISDN service will provide a wide range of applications in a public end-to-end digital communications network. An ISDN socket in the home or office would allow user connection of telephones, personal computers, display stations, and other devices. Existing circuit switched links, of which there are an abundance, provide the B channels of 64 k bits/second. Separate packet switches are added to provide the D channel service. The D channel is mostly used for signaling on the network. The true ISDN will evolve so that the B channels and D channels will be merged into the same switching equipment.

The amount of data to be transmitted in a WAN teleradiology network requires higher bandwidths than 128 k bits/second or 1.544 M bits/second. The ISDN standard supports clear channels which use packet switching for supporting fast facsimile, compressed video, and high-speed data. These channels are: HO (384 k bits/second), H11 (1,536 k bits/second), and H12 (1,920 k bits/second).

Fig 2. Architecture of the integrated services digital network.

Fiber Optics Networks

The primary application of optical transmission¹³ has been to extend the available bandwidth. This has resulted in increasing the transmission rates. Current systems have signaling rates that operate between 2 G bits/second and 4 G bits/second. The result of this higher transmission rate is that: the broad bandwidth services required for teleradiology applications are available; and the cost of using a 56 k bits/second (or 64 k bit/second) switched circuit is significantly reduced. The widespread deployment of fiber optics links has served to increase expectations for broadband services. Agreement was reached in CCITT on the definition of a broadband integrated services digital network (BISDN).⁵ This agreement for the Synchronous Digital Hierarchy (SDH) sets the transmission rates and signal formats for a digital broadband communications network. The transmission signal is called SDH-1 and has a rate of 156 M

bits/second. Interfaces to the users will be a packet-like protocol called Asynchronous Transfer Mode (ATM).

For long-haul communication networks, the Synchronous Optical Network (SONET) was recently adapted.¹⁴ The basic building block of the SONET signal hierarchy is called the Synchronous Transport Signal-Level 1. The STS-1 has a bit rate of 52 M bits/second and is synchronous with a network synchronization source. The levels of the SONET signal hierarchy are shown in Table 4. Products are under development for the use of SONET protocols.

A SONET-type of WAN network architecture is illustrated in Fig 3. The OC-N refers to "N" increments of OC-1, where OC-1 is a 51.84 M bits/second optical carrier path. The SONET D/I is a drop and insert multiplexer that functions as a digital switching system. The DS-3 digital service (45 M bits/second) is the current digital primary interface for a fiber optic terminal (FOT).

Table 5. Site Characteristics

Site	Distance from Academic Radiology Department	No. of Patient Beds	Radiology Procedures Per Day	Radiology Coverage	Images to be Transmitted Per Day
A	50 miles	50	30	One-half day	12
B	150 miles	100	150	1 Full-time radiologist	44
C	168 miles	84	150	1 Full-time radiologist	44

After the first year, only the hardware maintenance costs will be incurred.

Topology of WAN Teleradiology Network

The users of the WAN teleradiology network have decided that they want the network links to be fiber optics, since fiber optics will offer high data throughput rates. However, due to the locations of the sites, it is not possible to provide the entire network with fiber optics links. Figure 4 shows the portions of the network that are fiber optics, the remainder being provided by the local carrier service. Site A is 24 miles from the interface to the fiber optics network. Site B is 62 miles from the interface, and Site C is 80 miles from the interface. The local carrier service will provide the digital service from each site to the point of entry onto the fiber optics network. The cost incurred for this service is called access charge. It has been decided to use

a DS-1 service (1.544 M bits/second) for all links on the WAN teleradiology network.

Communication Costs

Communication costs are calculated for two types of DS-1 (1.544 M bits/second) service. The first type is a point-to-point T1 carrier service between each site and the academic radiology department. The second type of DS-1 service is an N $\times$ 56 k bits/second service. For this service a communications controller is used which, depending on the selected value of N, collects N-56 k bits/second switched links and sends the image data in frames over multiple links. At the receiver, the frames are reassembled into the correct image data.

The T1 service (same as DS-1 rates) monthly charges are shown in Table 6. Each site is charged an access rate and a per mile charge. The monthly charges for this service are shown

Fig 4. A WAN teleradiology network example for comparing costs.

Table 6. Communication Costs for DS-1 Service

Site	Megabits Transmitted Per Month*	Site Access Charges Per Month†	Site Access Charges Per Month for Central Site‡	T1 Carrier Costs Per Month§	N × 56 k bits per Second Costs Per Month
A	12,079	\$1,700	\$117	\$4,195	\$2,076
B	44,290	\$354	\$117	\$3,519	\$730
C	44,290	\$3,500	\$117	\$6,786	\$3,876

*Megabits per month = 20 days per month × images per day × 50.33 M bits/image.

†DS-1 access charges vary depending on available digital exchange equipment.

‡DS-1 access charges at the academic radiology department is \$350, each site being charged \$350/3.

§T1 carrier charges per month = \$1,810 + \$6.70 per mile + access charges per month.

||N × 56 k bits per second charges per month = access charges per month + tariff per minute × 1 minute per 60 seconds × 1 second/56 k bits × bits per month × 1.2. Where 1.2 is protocol overhead and tariff is \$0.06 per minute.

in Table 5. T1 service is a point-to-point service for 24 hours per day. Accordingly, there is considerable under-use for this type of WAN teleradiology network. Access charges will vary depending on the available digital switching equipment in the region of each site.

The second type of service, N × 56 k bits/second, takes advantage of the decreasing costs of switched 56 k bits/second service. These costs are decreasing due to the increased availability of this type of service primarily because of the large amounts of fiber optics cable. The idea is that the site selects a value of N (N = 1 is DS-0 service; N = 1, 2, . . . , 23) and transmits at that rate. The communication controllers for this type of service are based on VLSI technology. The monthly costs for this type of service are shown in Table 5. This type of service may be referred to as a "casual user" service since the user pays for access charges and actual use charges. It should be noted that this type of service is not point-to-point. That is, each site can transmit to any other location with DS-1 access capabilities.

DISCUSSION

The cost comparisons of the two methods of WAN teleradiology network service show the extremes possible with digital service. The example teleradiology network (Fig 4) is a mixture of a long haul fiber optics network and a local carrier access. The access charges vary not so much by distance as by the availability of digital exchange equipment. As fiber optics cabling is enlarged to include each of the example sites, then the monthly access charges will decrease. In our example, as often happens, Site B has a

low site access charge for T1 (or DS-1) service even though it is 150 miles distant from the academic radiology department. The local carrier is able to provide service to DS-1 access because the site is located in a region with a high concentration of digital exchange equipment.

The T1 service charges per month (Table 6) are for point-to-point, 24 hour per day use. It is clear that the megabits transmitted per month are an under-utilization of this type of digital service. Other functions, such as medical educational programs, could be shared and merged with the transmission of digital image data. A distinct disadvantage of the dedicated point-to-point WAN teleradiology network is its limited connectivity. To expand to other sites will require the installation of added point-to-point service.

The N × 56 k bits/second "casual user" type of service requires the same access charges as that of the T1 service. However, the user charges (cost per minute) are only for the time the line is actually used. It is clear that in our example (Table 6) the usage charges are minimal due to the small amount of data being transmitted. Hence, the N × 56 k bits/second scheme reflects mostly access charges. As the fiber optics cables become installed nearer each site, then the access charges for DS-1 service will approach \$350 per month.

It should be noted that the advantage of the N × 56 k bits/second switched service is that the user charges are independent of N. Hence the user cost for N = 23 is the same as the user cost for N = 1. The reason is that the time of transmission for large N's is shorter. This exam-

ple shows the many possible network protocols that are available due to the advancements in digital circuitry and the higher bandwidth from fiber optics networks. The one-time hardware cost to equip each site (Table 5) will decrease as the demand for WAN teleradiology networks increases.

Higher speed digital services, such as DS-3 service (45 M bits/second) are available, but are difficult to acquire in rural areas. Access charges

for this service will be much higher than those for DS-1 service (Table 6). However, as fiber optics networks are placed near each of the teleradiology sites, the access cost will decline. It is possible to implement the $N \times 56$ k bits/second controller scheme using DS-3 service. The OC-X SONET long-haul carrier will provide higher data rates for WAN teleradiology networks.

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