Telemedicine: Lecture Note

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1 Introduction

Telemedicine is the remote communication of information to facilitate clinical care. Since the inception of wired and wireless communication technology, efforts were made for providing teleconsultation on health care services. In early twenties of the last century, radio communication were used for providing clinical care to maritime sailors from the shore. Later in the fifties and sixties of last century, NASA took active interests for providing health care services to the astronauts in the space from the earth. Biomedical signals such as ECG, EEG, EMGs as well as physical parameters such as body temperature, pressure etc. were transmitted at regular intervals from the spacecrafts. Clinical advice was also given from the remote earth station. In 1970's satellites were used for guiding paramedics in sparsely populated regions of Alaska and Canada from city hospitals for providing health care services. Still in the past clinical telemedicine could not become a widespread phenomena. There were several obstacles preventing its wider usage. First, the cost of technology was very high and its access was restriced to a priviledged few. The reliability of functional componets for such a system were also low. Moreover, it required highly skilled manpower for their daily operation and maintenance. Due to the revolution in the digital communication and information technology in the last decade, telemedicine is getting applied more and more around the world in different areas of medical science and technology. Telemedicine systems are being used not only in advanced countries [Ist99], [Tak01], [CGC+01], but also in developing countries like China [HHLA01], Thailand [Kas01] etc. In India also, many systems are reported for their usage in clinical and diagnostic purposes [Jan01].

2 Core Technology

Telemedicine is the result of convergence of different technologies, namely *medical instrumentation*, *information technology,* and *telecommunication technolgy.* In this section let us briefly discuss some aspects and fundamental concepts related to these technologies.

2.1 Medical Instrumentation

Rapid advancement in medical instrumentation and technology has increased the reliability and accuracy of diagnosis of several diseases. In many cases a patient's physical presence is not required during the analysis of data acquired (apriori) by these instruments. Advanced medical imaging systems provide data such as *Computed Axial Tomographic (CAT)* Scan images, *Magnetic Resonance (MR)* images besides usual *X-Ray* images for the diagnostic purposes. Moreover, the data is available in the digital form by converting analog signal to digital sequences by *sampling* and *quantization.* Similarly, biomedical signals such as ECG, EEG, EMG etc. sensed by transducers in the analog form are also converted to digital data. One of the major advantages of digital representation of data is that associated patient's demographic and clinical information also could be coupled with it. This makes data processing and exchange of information much simpler. Different international standards are being developed for representing medical data and information such as *HL7, DICOM,* etc., so that different applications across different hardware platforms and software environment could interact with each other.

One of the key motivations of medical instrumentation in the context of telemedicine is the real-time transmission of data from the laboratories to distant places, so that the experts (pathologists, radiologists etc.) at remote ends could analyse the data on-line and provide their feedback and advice in real-time. The data size (specifically the rate at which it is generated during the acquisition) is the detrimental factor for designing such a system. For example, ECG data may be generated at a rate ranging from 1.6 Kbps (Kilo bits per second) to 8 Kbps. The *sampling rate* (number of samples per second) and the *quantization level* (proportionality factor for converting discrete numerics to the actual sample value) determine the data size during digitization. The sampling rate (or *sampling frequency*) is determined by the *bandwidth* of a signal. According to *Nyquist theorem*, for a band-limited signal (true for any signal generated from physical processes), the *sampling frequency* is twice the bandwidth of the signal. For a ECG signal the bandwidth is approximately $100Hz$. Hence the minimum sampling rate for digitizing the signal is 200 samples per second and if one maps the analog values (in milivolts) in one of 256 discrete levels, it requires 8 bits per sample to represent the data. Subsequently, the minimum data rate at which ECG signals could be acquired is 1.6 kbps. Similarly, for simultaneous transmission of 12 channel ECG a minimum data rate of 15.2 kbps is required. Still images and videos require much larger data rate for real time transfer of data. Typically, a video with moderate resolution (with a frame size of 480×640 pixels and at a rate of 15 frames per second) requires a datarate of 110.6 Mbps for real time transfer. A very high speed communication link can only afford such a high data rate. The technology is costly and may not be available always. Hence, the data has to be compressed (with an acceptable level of degradation in the visual quality) before its transmission. Three-dimensional sectional images such as CT, MR etc. require much higher bandwidth. It may be noted that if real time transfer of data is not required, one may transfer this data over a low speed communication link such as telephone lines, which naturally takes significant amount of time (say for hours) in transmission.

2.2 Information Technology

Information technology concerns with representation, storage, retrieval, processing, communication and presentation of data. Multimedia systems coupled with back-end database servers are providing now cutting edge technological solutions in the area of man-machine interactions and exchange of information. Graphics hardware and display monitors are not only capable of displaying colored images and videos captured through digital still and movie cameras, but also are used for rendering realistic images and animations empowering human perception and understanding about a process or a phenomenon. There is a rapid advancement in the computing power of these systems as well as in computation techniques for processing multimedia data in the form of text, audio, image, video etc. Moreover through computer networking the systems could interact with each other by exchanging information and messages. Telemedicine is one such application.

One of the important tasks while working with multimedia data is to keep adherence to an international standarad or format of data representation. This makes system integration simpler and effective. The standards are not anly meant for accomodating different types of information related to the presentation and content of the data, but also they are often required to describe the data in an alternate way. These alternative descriptions are specially required while compressing multimedia data. For example, for audio, MPEG is a commonly used standard. Similarly image standards such as JPEG, JPEG-2000 etc. are used for representing digital images and MPEG-II, H.263 etc. are used for video compression. One of the key characterization of these compression techniques is whether they are *lossy* or *lossless* schemes. In a lossy compression scheme recovered data after decompression is an approximation of the original one. The degree of approximation determines the quality of the data. Audio and video data used for video conferencing during telemedicine sessions are compressed using lossy schemes such as MPEG. On the other hand, digital images used for diagnostic purposes are required to be transmitted without any loss of any information. Hence lossless or semi-lossless (e.g *JPEG-LS*) schemes are employed to them, even though there are many practical telemedicine systems where lossy compression schemes (such as JPEG) are used to save the bandwidth of transmission. Lossy compression techniques provide higher compression compared to lossless ones. Band-width requirements (expressed in terms of bits per second) of different multimedia data even after compression are shown in Table 1.

Table 1: Band-width requirements of different compressed multimedia data

Type of Multimedia Data	Bandwidth
Usual data	100 bps $\sim$ 2 Kbps
Image	40 Kbps $\sim$ 150 Kbps
Voice	4 Kbps $\sim$ 80 Kbps
Stereo Audio	125 Kbps $\sim$ 700 Kbps
VCR quality video	1.5 Mbps $\sim$ 4 Mbps
3D medical images	6 Mbps $\sim$ 120 Mbps
HDTV	110 Mbps $\sim$ 800 Mbps
Scientific Visualisation	200 Mbps $\sim$ 1000 Mbps

2.3 Telecommunication Technology

Telecommunication technology deals with transmission of signal through a communication channel. For transmission of digital data, one requires to convert or encode the data into analog signal or symbols. Similarly, at the receiving end, the encoded analog signal is decoded in the form of digital data. As the bandwidth of the signal may not fall within the bandwidth of the communication channel, it is required to process it so that the processed signal becomes elligible for transmission. The operation is known as *modulation*. Similarly, at the receiving end, the process of recovering the signal from the modulated one, is known as *demodulation*. Usually, in a modulation technique, a carrier sinusoidal signal is used whose amplitude, frequency or phase are modulated by the input signal. Depending on the type of modulations they are referred as *amplitude*, *frequency* or *phase* modulation.

Ordinary telephone lines are used for transmission of voice signal whose bandwidth is approximately 4Khz. Telephone lines also operate in the same range. Hence no modulation-demodulation is required in analog telephony. However, in digital telephony and data transmission through telephone lines, one requires to convert digital data to analog symbols suitable for transmission. Signal modulation is used for this purpose. That is why *modems (Modulator and Demodulator)* are used as interfacing devices between a computer and a telephone dial-up line for data communication.

If the channel bandwidth is not sufficient for handling the signal bandwidth the signal will be distorted at the receiving end and there will be loss of information. Hence bandwidth of a communication link is a key technical feature determining its usage for data transmission. For example, a real time television standard video transmission requires about 7.5Mhz. bandwidth and could not be transmitted through usual telephone lines. However low quality video transmission is possible at much lower bandwidth. In the context of digital transmission bandwidth is expressed in terms of bits per second (bps). Using a modem in ordinary telephone line on the average a data rate of 30 Kbps (maximum 57.6 kbps) could be achieved. Hence, real time MPEG-I video at a rate of 1.54 Mbps will not be transmitted through this link. On the other hand a T-1 telephone link supporting 1.54 Mbps will be just enough for transmission of such video. For supporting higher bandwidth and datarate, optical communication technology is increasingly used. Data transmission rate as high as Gigabits per second could be achieved using optical communication links. There are different digital telephone services available from the telecommunication service providers (such as BSNL) at different rates. They are summarized in table 2.

Table 2: Different Communication Links

Links	Bandwidth
POTS	2.4 Kbps $\sim$ 57.6 Kbps
ISDN (BRI)	128 Kbps
T-1 and fractional T-1	384 Kbps $\sim$ 1.54 Mbps
DSL	128 Kbps $\sim$ 9 Mbps
Primary rate ISDN	1.54 Mbps
T-2 leased lines	6.312 Mbps
T-3 leased lines	46 Mbps
T-4 leased lines	273 Mbps
Broadband ISDN	150 $\sim$ 1200 Mbps
SONET	51.84 $\sim$ 4976 Mbps

Table 3: Different Wireless Communication Services

Links	Bandwidth
GSM	9.6 Kbps $\sim$ 43.3 Kbps
GPRS	171.2 Kbps
Satellite	2.4 Kbps $\sim$ 155 Mbps

Apart from wired links, wireless communication is also used for this purpose. Interestingly mobile telephone services are also used for data communication. In Table 3 the datarates supported by different wireless technologies are summarised.

2.3.1 Computer Networking

Computer networking connects a group of computer for exchange of information. Data communication can take place following some protocols, understood by all the participating nodes. There are different roles that a node could play in this network. For example, it could be a terminal host computer where applications such as telemedicine are running or it could function as an exchange for establishing communication channel between two terminal hosts. International Standarad Organisation (ISO) has defined 7 layers Open System Interconnection (OSI) protocols for data communication. Starting from layer one they are named as protocols for *physical* layer, *datalink* layer, *network* layer, *transport* layer, *session* layer, *presentation* layer and *application* layer. Higher layers deal with communication of data directly related to users, applications, processes etc., while lower layers deal with the protocols for basic signalling, channel sharing and routing. Protocols at lower layers are more integrated with network architecture and topology. Computers may be connected through a grid of point-to-point connections between two nodes (like a telephone network). They may share a common coaxial cable for transmission and reception of data (bus topology). They may form a ring where each node of the ring is connected to two computers or nodes (ring topology). They may also be connected to a switch (star topology) like the local loops in a telephone exchange. Depending upon the area of coverage different networking technologies are available. Local area networking (LAN) is used for a campus, organisation etc. Wide area networking (WAN) is used for connecting computers situated in different geographic locations. There are different LAN options available on bus architecture (Ethernet and Token Bus protocols), ring architecture (Token Ring Protocol), tree architecture (nodes acting as switches, e.g ATM cell switching, Gigabit Ethernet protocol etc.). Data rate supported by different protocols are listed in Table 4.

Table 4: Data Rates Supported by Different LAN technologies

LAN Technology	Datarate
Ethernet	10 Mbps
Token ring	$4 \sim 16$ Mbps
Token bus	16 Mbps
ATM	155 Mbps
Gigabit Ethernet	1000 Mbps

Wide area networking (WAN) technlogies are usually based on different services (such as local loop subscriber, ISDN, DSL etc.) available on conventional telephone lines, whose bandwidth may be significantly enhanced by the use of optical fibers. In advanced countries, there are also special communication networks with different architecture (say ring architecture) linking different service stations in a large area for supporting higher datarates. Data communication takes place using different protocols such as SMDS, Frame Relay, Synchronus Time Division Multiplexing (in SONET) etc.

3 Medical Informatics

Medical informatics is the subject covering representation and computation on medical and health information. They are targetted at design and development of information system for medical science and technology, health care services and business etc. There are different international standards for exchange and management of information related to these areas. These standards are developed so that the systems designed by different organizations and running on different platforms could interoperate with each other. For example, a hospital may require to send information and query regarding a patient to another referral hospital. On the otherhand, for getting payment from an insurance company, the hospital may require to send relevant information (related to services and their charges) to them. As different information systems are operational at different sites, there should be a common language for exchanging messages and queries, as well as a common format for representing patients' data. Two such standards have become very popular in medical business world. One is known as HL7 (Health Level 7), a messaging protocol specifically developed to exchange health / medical / patient information between information systems. The other one is DICOM (Digital Imaging and Communications in Medicine) standard for representing medical images, waveforms etc.

3.1 HL7

Health Level Seven is one of several ANSI-certified Standards Developing Organizations operating in the healthcare arena. Its aim is to provide standards for the exchange, management and integration of data that support clinical patient care and the management, delivery and evaluation of healthcare services.

Unlike other health standards which focus on requirements of a particular department, HL7 is singular as it focuses on the interface requirements of the entire health care organization. Consider, for example, a case of a patient's admission to hospital. The Patient Administration System (PAS) records details about the patient (demographics), and the admission (admitting doctor, ward, financial details). There is likely to be several other systems such as Pathology Laboratory Information System or Pharmacy System, which will be interested in these details. So a message to each of the interested systems in the hospital about the patient needs to be sent from the PAS. Or alternatively, the systems may wait until they need to provide a service to the patient, and then send a query to the PAS for details. Whether the details are delivered via an announcement from the PAS or in response to a query, the PAS needs to communicate information about a patient to several different systems. Before HL7 was developed, vendors of information systems that needed to communicate had to get together and work out what information to send each other and how it should be formatted, and then develop a new interface mechanism. This is an expensive and time-consuming process. HL7 was developed to provide a common language for Health/ Medical-based information systems for exchanging and sharing of information.

3.1.1 Messages

HL7 messages are generally created and sent by an information system in response to an *event* occurring. The event might be something such as a patient admission, a pathology result finalized etc. It may also be a query from another system. Each *message* contains information about that event. Each HL7 message is made up of *segments*. Segments are the building blocks of HL7 messages. Each segment has a three character code and a pre-defined format of specific *fields*. The segments are terminated by end of line (or carriage return) character. Every message starts with a *message header segment* (denoted by the code 'MSH'). The fields are separated by the `|` (pipe) character, and may be further divided into *components* (with the `^` character) and *subcomponents* (with `&` character). A sequence of data values is usually separated by the character `~`. These encoding characters are defined in the message header of the segment. All data are represented as displayable characters from a selected character set. The ASCII displayable character set is the default character set.

Segments group related information together. For example, the PID segment contains information to identify a single patient, such as ID numbers, name, address and date of birth. Different HL7 events trigger different message types. Each message type has a defined set of segments that are joined together to provide all the required information regarding that event. Some segments are mandatory, and must be included in the message. Other segments are optional. For example in the event of "Admission and Visit Notification" (ADT message), minimally four segments (Message Header (MSH), Event Type (EVN), Patient Identification (PID) and Patient's Visit (PV1)) are required. But there may be many other optional segments containing information about a patient's next of kin, disability, allergy, previous diagnosis etc. Similarly, a segment is constructed as a sequence of data *fields*, some of them are mandataory. If there is no information for an optional field, field separator symbols are simply repeated. However, the sequence is terminated as soon as there is no other data field containing any valid information. For example in the PID segment, though there may be as many as 30 fields, only two of them (Patient's Internal ID and Patient's name) are minimally required for forming the segment. As they occupy third and fifth places respectively, a valid PID segment may look as given below:

```
PID|||2-687005||Dutta^Nirmalya
```

A simple example of HL7 message related to the event of patient's admission/ transfer is given below:

```
MSH|^~\&|Clinic||Central|Reg|||ADT^A01|MSG00005|P|2.3
EVN|A01|199601051530
PID|||2-687005||Evans^Carolyn||19620324|F|||903 Diane Circle^^Phoenixville^PA^19460
   ||(610)555-1212|(610)555-1212||S|C||156-96-2542
PV1||E|Emergency||||0148^Addison^James|||SUR
```

The message could be interpreted in the following format:

Admit/Visit Notification

1. **Message Header**
   (i) **From: Clinic**
   (ii) **To: Central**
2. **Event**
   (i) **Date: 1996-01-05**
   (ii) **Time: 15:30**
3. **Patient Identification**
   (i) **Internal Patient ID Number: 2-687005**
   (ii) **Family Name: Evans**
   (iii) **Given Name: Carolyn**
   (iv) **Birth Date: 1962-03-24**
   (v) **Sex: F**

(vi) **Street Address: 903 Diane Circle**

(vii) **City: Phoenixville**

(viii) **State or Province: PA**

(ix) **Zip or Postal Code: 19460**

(x) **Phone Number Home: (610)555-1212**

(xi) **Phone Number Business: (610)555-1212**

(xii) **Marital Status: S**

(xiii) **Religion: C**

(xiv) **Social Security Number: 156-96-2542**

4. **Patient Visit**

(i) **Patient Class: E**

(ii) **Point of Care: Emergency**

(iii) **Attending Doctor's ID Number: 0148**

(iv) **Family Name: Addison**

(v) **Given Name: James**

(vi) **Hospital Service: SUR**

3.1.2 HL7 & Telemedicine

The advance of regional health care networks has created increasing demand for telemedicine services tailored to particular medical specialties and health care settings. At the same time, emerging telemedicine protocols and guidelines combined with various medical standards provide specifications not only for the exchanged clinical content but also for the physical setting and technology in use. Accountable telemedicine services require detailed records for the telemedicine sessions. Besides the management of data necessary for the assessment and reimbursement, telemedicine records also include clinical data such as consultation request, diagnostic examinations (x-rays, ECG, etc), diagnostics reports etc. Since telemedicine records outlive the session in which they were created, clinical documents and other objective medical data need to be in a standard format to facilitate portability and accessibility. Each telemedicine service uses a set of clinical document templates which are submitted before or during a telemedicine session. Clinical document templates correspond to structured forms that are filled out by healthcare professionals in the context of telemedicine. These clinical documents can use HL7 standards for transferring information.

3.2 DICOM

The DICOM (Digital Imaging and Communications in Medicine) Standard is developed with collaborations from American College of Radiology (ACR), American College of Cardiology (ACC), American Society of Echocardiography (ASE), European Society of Cardiology (ESC), American Society of Nuclear Cardiology (ASNC) and the National Electrical Manufaturer's Association (NEMA). The standard was previously known as ACR/NEMA standards. Subsequently with considerable revisions and supplementation the standard is renamed as DICOM in 1991. In its present release DICOM conformance statement comprises of 13 parts covering various issues such as information object definitions, service class definitions, data structures and semantics, data elements listing and typing, message exchange protocol, network support for message exchange, point-to-point support, media storage and file format etc.

A DICOM file consists of a preamble (of 128 bytes), a prefix (4 bytes denoting 'DICM' as identification to DICOM standard) and a list of data elements. Each data element encodes the necessary information related to a patient and data organization in the file. A special data element called 'Transfer Syntax' is used for describing how the fields in a data element are to be interpreted. There are two methods for representng a data element, namely *explicit value representation* and *imlicit value representation.* In the first case data types of the values are explicitly mentioned. In this case a data element consists of four fields, namely *tag* (4 bytes), *value representation* (VR of 2 bytes), *value length* (VL of 2 bytes) and *value field* (VF of an even number of bytes as mentioned in VL). For implicit value representation default data type is assumed and it is not mentioned in the data element, which is described by three fields, such as tag (4 bytes), VL (4 bytes) and VF. A tag bears the identity of a variable whose value is stored in the element. It is encoded by a group code (of 2 bytes) and an element code (of 2 bytes). For example, a patient's name is under the group patient and encoded as $(0x0010, 0x0010)$. In this case the patient group is identified by its *group code* $(0x0010)$ and patient's name is identified by the *element code* of that group $(0x0010)$. Some of the interesting groups are given in table 5.

Table 5: Typical groups in DICOM Standard

Group Name	Hex Encoding
File Meta Information	0x0002
General Series Information	0x0008
Patient Information	0x0010
General Study Information	0x0020
Image Information	0x0028
Image pixel data	0x7FE0
Waveform Information	0x5400
Equipment Information	0x003A

Similarly, some important elements for rendering an image in DICOM format are listed in table 6.

Table 6: Some vital tags for rendering images in DICOM Standard

Tag Description	Hex Encoding (Group, Element)
Transfer Syntax Tag	(0x0002,0x0010)
Samples per pixel	(0x0028, 0x0002)
Number of Frames	(0x0028, 0x0008)
Number of Rows	(0x0028, 0x0010)
Number of Columns	(0x0028, 0x0011)
Number of Bits Allocated	(0x0028, 0x0100)
Number of Bits Stored	(0x0028, 0x0101)
Pixel Data	(0x7FE0, 0x0010)

DICOM Standard also defines different type of services, formally known as service classes. The services could be about storage, query and retrieval of data. It could be also for providing hardcopies (prints) of images. DICOM service classes for managing different schedules are also available. These service classes are known as SOP classes and each service has an unique identifier.

4 Telemedicine Systems

Telemedicine systems are being used from the early twentieth century. Many of the systems were experimental and built up to provide the proof of concepts. This is true even for today, though commercial application of telemedicine systems are increasingly getting reported.

4.1 Early Telemedicine Systems

Interestingly the inventor of electro-cardiography (ECG) Einthoven [Ein06] used telephone lines for transmission of ECG signals as early as in 1906. The reason for using telephone line in his time was that the cost of the galvanometer designed by him, was much higher than telephone charges. Even when cheaper technology was made available, in 1920's ECG and EEG were transmitted from diagnostic laboratory to distant places using telephone line in USA. During the same period, medical advice were provided to sailors from off-shore physicians using telegraphy and radio transmission of voices. There are also reports of use of telecommunication technology for the purpose of medical consultations from USA in subsequent decades. In 1950's, telepsychiatry between a state mental hospital and the Nebraska State Pshychiatric Institution [HH00] was operational using microwave communication links. During the same period NASA and US Public Health Services devloped a joint telemedicine programme to serve the Papago Indian Reservation in the state of Arizona[HH00]. In 1960's closed circuit televisions wers used for point to point conferencing between doctors. In 1970's paramedics in remote Alaskan and Canadian villages are connected to urban hospitals using ATS-6 satellite systems [DCZ75]. In Japan experiments on telemedicine [Tak01] were started as early as in 1970's using telephone lines and cable television system. Telemedicine is increasingly used after 1990's due to the rapid advancement in digital technology and availability of this technology at a much lower cost in comparison to earlier systems.

4.2 Present Day Systems

Though the reports of early systems are mostly from USA, presently use of telemedicine systems are reported around the world. A few of these are discussed here.

A telemedicine network [ea01] is established in Japan for the purpose of education and training of medical professionals. Initially, in 1994 the system was built up by connecting National Cancer Centers in Tokyo and Chiba, separated by a distance of 30 Km. An optical leased line with 6 Mbps data rate was used for data communication. Later the link was upgraded to support 18 Mbps data transfer rate using ATM protocol. Additionally an experimental line with 156 Mbps band width (B-ISDN link) is used for improving the quality of services. In later years, the network is grown to include more regional cancer centers (as many as 14 as reported in [ea01]) using frame relay communication services. The system is equipped with TV conferencing. The participants can discuss with a still image using a HDTV image sharing technology. Regular conferences on nursing, radiology, oncology, pathology etc. are held using this network with an annual participations of more than 15000 people.

In Lincolnshire, U.K., telemedicine is being used for handling accident and emergency cases [BMG01] since 1996. In this system, two Minor Injury Units (MIU) at Skegness and Johnson are connected with a District General Hospital (at Boston) via an ISDN (128 Kbps) line. A desktop video conferencing unit with store and forward image transfer on a Pentium PC is used in this case. There are also other peripheral devices such as scanner, digital camera etc. The system is mostly used for handling othopaedic emergency cases. Patients predominantly with fractures, sprains, strains and laceration are treated by the system, which involve online transmission of X-Ray images.

A telepathology experimentation [ea02b] for demonstrating its viability is reported from Korea using store and forward technology. Pathological slides were captured by a microscope attached digital camera with a phototube adapter at Samsung Medical Center, Seoul and were sent to two different places, namely at Korea University Hospital, Seoul and at John Hunter Hospital New Castle, Australia. Additionally, the slides were sent also to an independent pathologist. The images were compressed by JPEG compression scheme at moderate quality. It has been observed that there is a high degree of concurrence of pathological reports with the independent reports (by directly viewing the slides). For Korea University Hospital the diagnosis was made with 95% concurrence and for John Hunter Hospital it was with 97% concurrence.

Real time transmission of pediatric echocardiograms [ea02a] on ISDN link is reported from Duke University Medical Center, Durham, North Carolina. The center acts as a referral center for nine small centers equipped with a USG imaging system and a cardiologist (for adults) , but without having any specialist for pediatric echocardiography. The subcenters are situated at a distance from 9 Km to 200 Km (on the average 160 Km). Video conferencing (Picture Tel 550) is used for transmission of cardiograms at 15-18 frames per second. The performance of the system was evaluated by independent study of the recorded (videotaped) cardiograms by an pediatric cardiologist during the period between January'1998 and January'2001. There was concurrence of reports in 383 cases out of 401. Usually, colored Doppler images are difficult to interpret using the system.

A telemedicine network on T1 leased line and ISDN link is established in Taiwan [LCCS01] for clinical consultations. The National Taiwan University Hospital (NTUH) acts as a referral center in this network and it is connected to several other remote sites, e.g. with Chinshan Health Station and National Chung Kung Univesity Hospital. At NTUH a multimedia database is used during teleconferencing session. Images in different modalities such as CT, MR and X-Ray are represented by DICOM 3.0 standard. Videos of USG, endoscopes etc. are transmitted using MPEG compression. The system has also the feature of store and forward image transfer. Feedback from patients, consulting phyicians and consultants were taken on the utility of the system. A high degree of acceptances was reported for all of them.

5 TelemediK: a low cost scalable telemedicine system

At the Indian Institute of Technology, Kharagpur, a telemedicine system [MMB+01] has been developed for the treatment of tropical diseases such as leprosy and other skin related diseases etc. Later the system is extended to different other areas of medicine such as teleradiology. The system is known as TelemediK and its advanced version (ver. 3.3) is currently released for its wider usage. In a country like India, where basic health care facilities are poor and people have to travel a lot for obtaining expert opinion and the treatment for a disease, telemedicine would be a great help to the common people. Here too, one should keep into consideration of the following facts which are relevant in the Indian perspectives. They are:

1. Low communication infrastructure: The telemedicine has to run on POTS or at the most, on ISDN channels. This imposes severe bottleneck over the on-line conferencing session. The

quality of video and audio suffers a lot. The transfer of large data file such as images and videos during on-line session should be discouraged, as they will take considerable time.

2. A large population: Unlike in many telemedicine system, our system is expected to handle a good number of patients per week. Hence efficient resource management (specially, the available manpower) is required.

These are given due considerations in the design of the system. The technology adopted in system integration is relatively cheaper. It could run on ordinary IBM PC with MS-Windows environment and with a backend MS-SQL RDBMS Server. This also keeps the maintenance cost low. The system could operate with low cost peripheral equipments such as ordinary digital camera, scanner, web cams etc. Secondly the running cost is also less because of the use of ordinary telephone lines. The system is scalable enough to accommodate higher bandwidth communication links such as ISDN, leased lines etc. The system is presently operational between the School of Tropical Medicine, Kolkata (acting as referral institution) and Habra State General Hospital, 24 Parganas(N), and Cooch Bihar M J N Hospital, Cooch Bihar (acting as nodal centers).

Telemedik has adopted the store and forward mechanism for data transfer that efficiently uses the low bandwidth communication channel. Besides this, it also provides on line data conferencing with text and images. Doctors at two ends can discuss among themselves in real time using the on line communicator module. The system operates with image standards such as DICOM, JPEG and BMP. In one year more than nine hundred patients have been treated by the system. About 80 % of them are suffering from different chronic diseases like dermatological and blood related diseases. Patients normally get feedbacks from the referral center within three days from the date of sending medical records from a nodal center. Presently, installation of Telemedik at different district hospitals and medical colleges are going on for the purpose of teleradiology. A brief description of the system is given in the following subsections.

5.1 Principles of Operations

One of the objectives in the working of the system, is efficient utilization of available bandwidth which may be as low as supporting a data rate of 5 Kbps. In our experimentations while trying to communicate between two ends separated by a distance of more than 300 Km using an ordinary telephone line, we have observed that the effective data rate supported by a 56 Kbps modem is around 10 Kbps in the day time. Hence in its operation one should keep the the real-time bandwidth requirement as low as possible. For this the bulk of the patient information is collected before the telemedicine session. Information such as patient's history, signs and symptoms, old prescriptions, diagnostic test reports and images etc., are transferred before the start of the conferencing. It may be noted that this data transfer does not have any real-time constraint. The data could be transferred for a longer duration. Specially, when the communication channel is relatively free (say at night), the data may be transferred. This type of transfer of data is referred as *off-line data transfer*.

The off-line data transfer requires systematic organization of patient data, which should be understood at the both end. The data should also be kept according to some convention in the disk, so that patient-wise access of the data-files during browsing and conferencing becomes easy.

A browser for browsing through the patient's data is also provided. This enables the expert physician to form the opinion about the patient before the start of the session and also to filter out some cases, which may not demand *on-line* telemedicine session. Based on these telemedicine operations are performed according to figure 1. A schematic diagram of the hardware configuration is also shown in the figure 2.

5.2 The Data

Let us consider different types of data used in the system and discuss how they are represented. In our system the data is categorized into five classes:

1. **Data related to a patient's personal information**: This category includes the information related to a patient's name, address, sex, age etc. But, the more important is an unique identity number (called as *Pat_Id*) given to a patient by the system.

2. **Data related to a patient's medical information**: There could be various types of medical information for a patient in various forms, such as, ordinary text (e.g. prescriptions), structured text (e.g. test reports), digital images (e.g. XRay's), graphics primitives (e.g. polygons, lines etc.), graphs (e.g. ECG's) and video clips (e.g. ultra-sonograms).

3. **Data for patient management in telemedicine**: For maintaining the current list of patients waiting for telemedicine, the information about these patients are stored in a *Patient_Queue*. It may be noted that a patient is enqueued in the *Patient_Queue* as and when *new* patient data entered into the system for nodal (through data organizer) and referral end (through data transfer). Similarly, after the end of telemedicine for a patient, the data is deleted from the patient queue. The system administrators are also given the power of addition and deletion of any patient in the patient queue as and when required. The patient queue is also used by the off-line browser for browsing the patient data. The session scheduler also schedules the telemedicine sessions for a day from the information available in the patient queue.

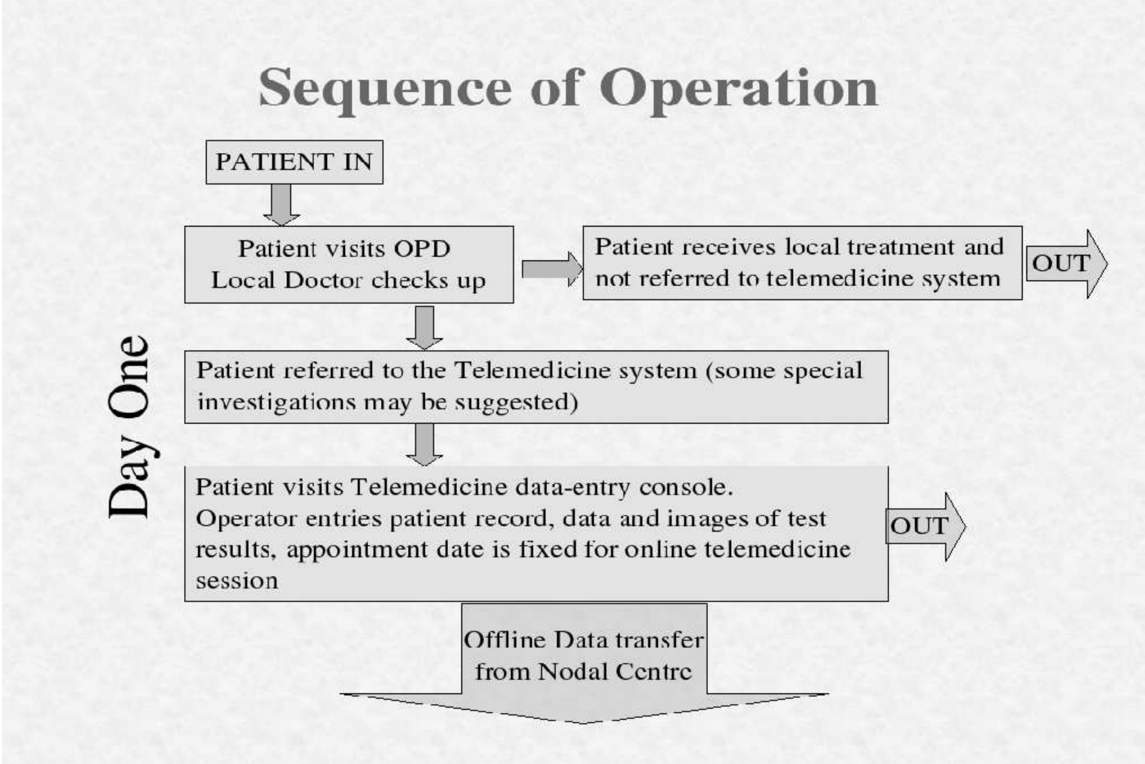
4. **Data related to the physicians**: The physicians personal information and an unique identification key are also used in the system.

5. **Data for system management**: For system management, the list of users at different levels are to be maintained. Their passwords are also to be managed by the system. Besides, maintaining the valid users' list, the system also maintains the log files for data transfer, on-line telemedicine session etc.

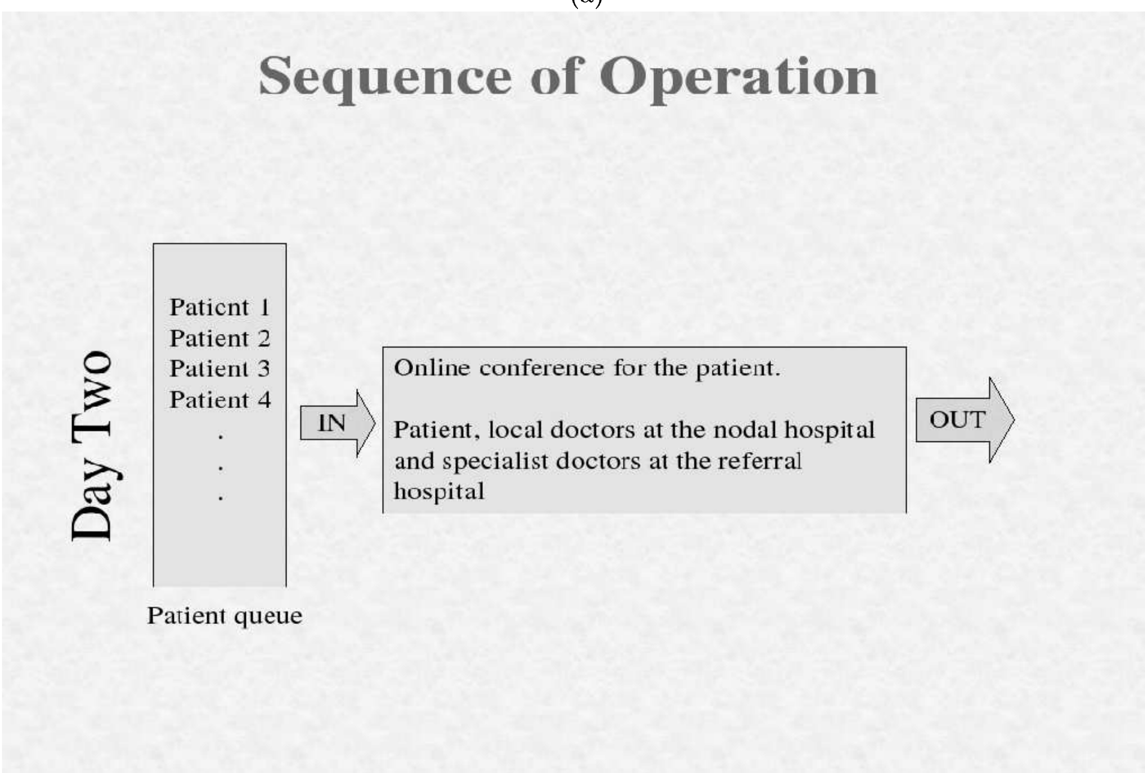
5.3 The Database

The patient's data are stored in a database. For this purpose an RDBMS (typically SQL Server 2000) is used. Both the nodal end and the referral end has this database. It may be noted that the data are stored in the distributed fashion. The medical information for individual patients are stored in the nodal center, while all the patients' list, data related to their visits etc. are stored at the referral center. The list of doctors for individual centers are also stored separately at respective places. There are different relational tables used for this puprpose, such as, *the patient-table*, *the physician-table*, *the tables related to the diagnostic test reports, images and leprosy patches of patients*, and *a table related to the visit of a patient in the telemedicine system.*

The database supports basic operations such as *data-insertion*, and *data-retrieval. Data-insertion* takes place during the distribution of patient data. Hence the data distributor module takes care of this. There are also related data to be stored during on-line telemedicine session (updating visit table etc.). The system administrator is also given the power of inserting patient data from the



(a)



(b)

Figure 1: Sequence of Operations

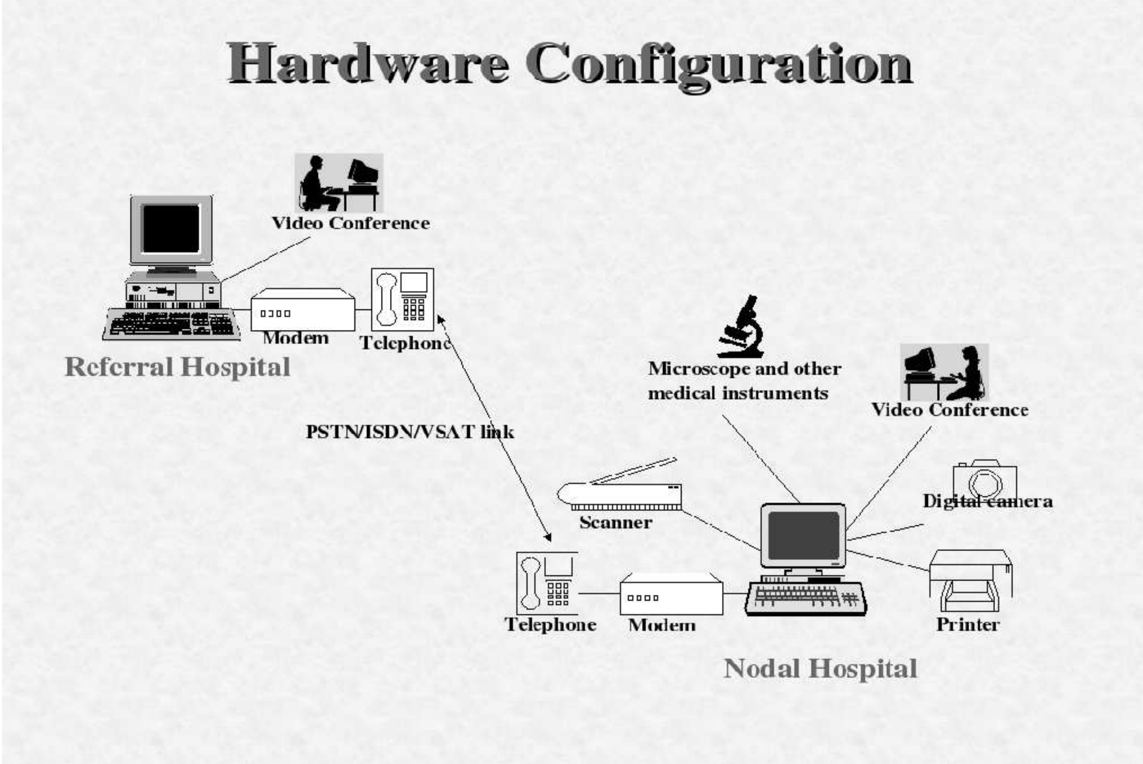


Figure 2: Hardware Configuration

working directories of a patient. *Data-retrieval* could be done as and when required in the form of different queries. There are *four* basic forms of retrieval related to a patient such as, retrieval of all the medical information related to a patient, retrieval of medical information of a specific type or category for a patient, retrieval of a specific medical information for a patient given its unique key (type, date and the sequence number), and retrieval of information of a patient related to a specific visit or a set of visits. The database also supports generation of different statistics related to telemedicine.

5.4 Off-line Operations

As described before the system works with the principles of both store and forward operations and live conferencing. These operations are categorized here as off-line and on-line operations. In this section, we will describe briefly different stages of off-line operations. A schematic diagram of its different stages are shown in Fig. 3

1. **Data Acquisition**: This module handles with data entry for a patient's personal information, test reports, scanned and digital images, scanned documents, video and audio clips, ECG reports and graphs etc. There is also the provision for drawing leprosy patches on the human profiles as shown in Fig. 4. The drawn patches are stored as contour points.

   Patient registration also takes place in this module. A patient identitifaction number (referred as Pat_Id in the system) is automatically generated for every new patient. For an old patient (identified by the Patient Id) the personal information are displayed for verification. The Pat_Id for a new patient is automatically generated by the system.

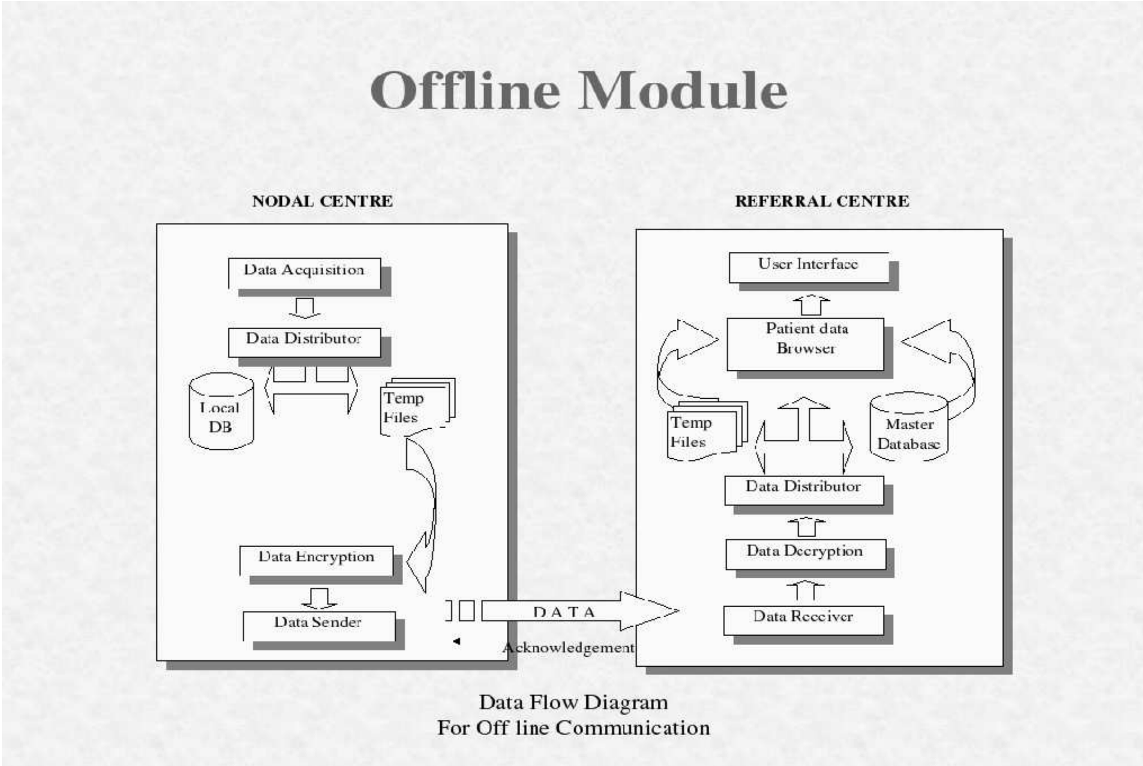


Figure 3: Off-line Operations

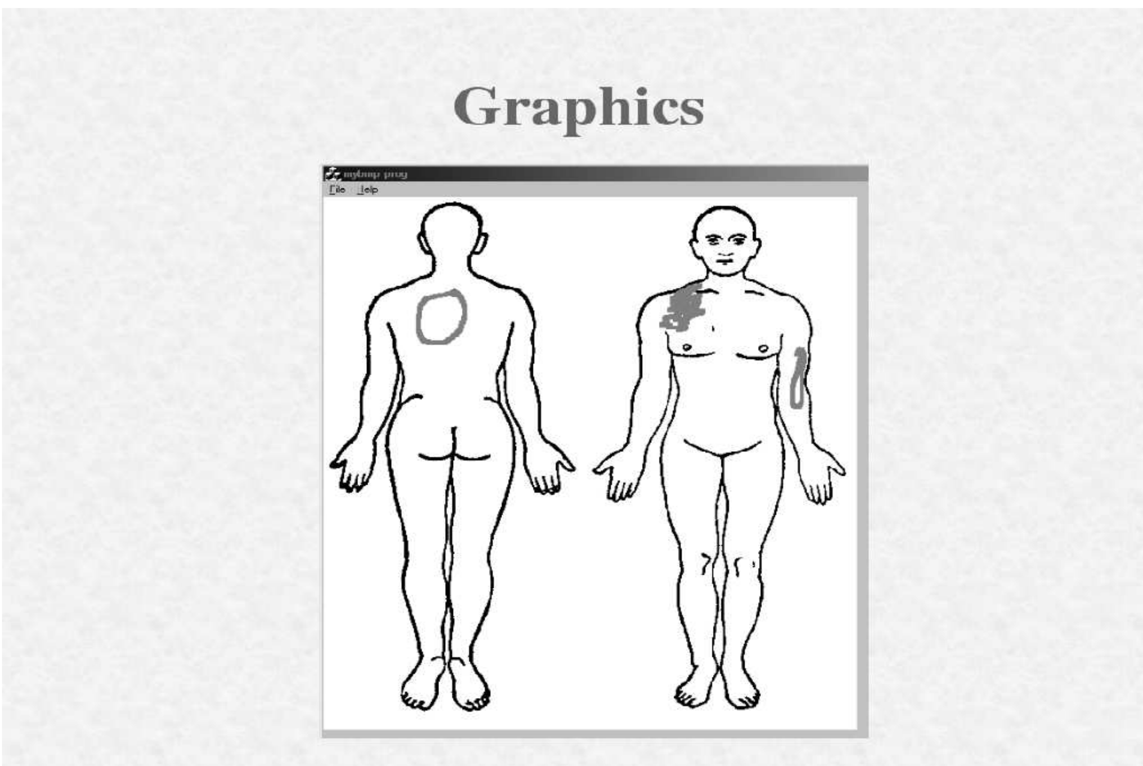


Figure 4: Leprosy patches: represented as contours

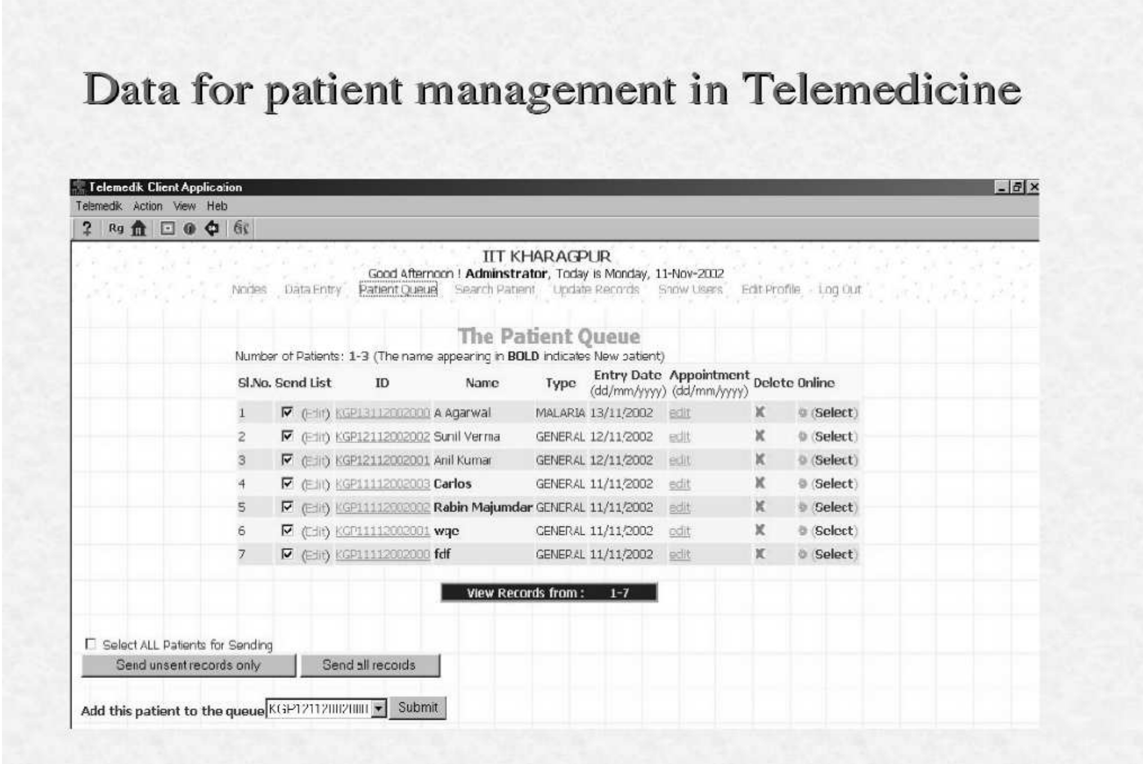


Figure 5: Management and browsing of patient data

2. **Data Distributor**: The data distributor distributes the organized data as patient wise in the file system as temopary files and also stores the data in the database. The files are later sent to the referral end using *ftp* services. It may be noted that the data distributor also updates the patient queue at the nodal end. At the referral end, the system administrator is required to perform this task.

3. **Data sender**: The Off-line sender sends the files to the referral end, keeping the directory structure as it is. At the end of the transfer (or at any interruptions in between), the sender produces a log recording the successful transmission and also the failed transmission. The system automatically detects these files and transfer them by the subsequent requests. While sending the data, they are compressed by a lossless scheme and subjected to a public encryption policy.

4. **Off-line browser**: The physicians at the both ends browse the patients data using off-line browser. The browsing is carried out with the help of *patient queue*. At the referral end, the system administrator has to update the patient queue before browsing any newly received data. The patients' list is dynamically created from the patient queue according to the type of disease. A typical front end for browsing patients' list is shown in the Fig. 5. It may be noted that using the same front end the system administrator also manages various operations such as fixing appointments for a patient with a doctor, inclusion and removal of patients in the patient queue etc.

There is also an *administrative module* for the system administrators, which could perform various tasks such as maintenance of system configuration files, providing access permissions, managing

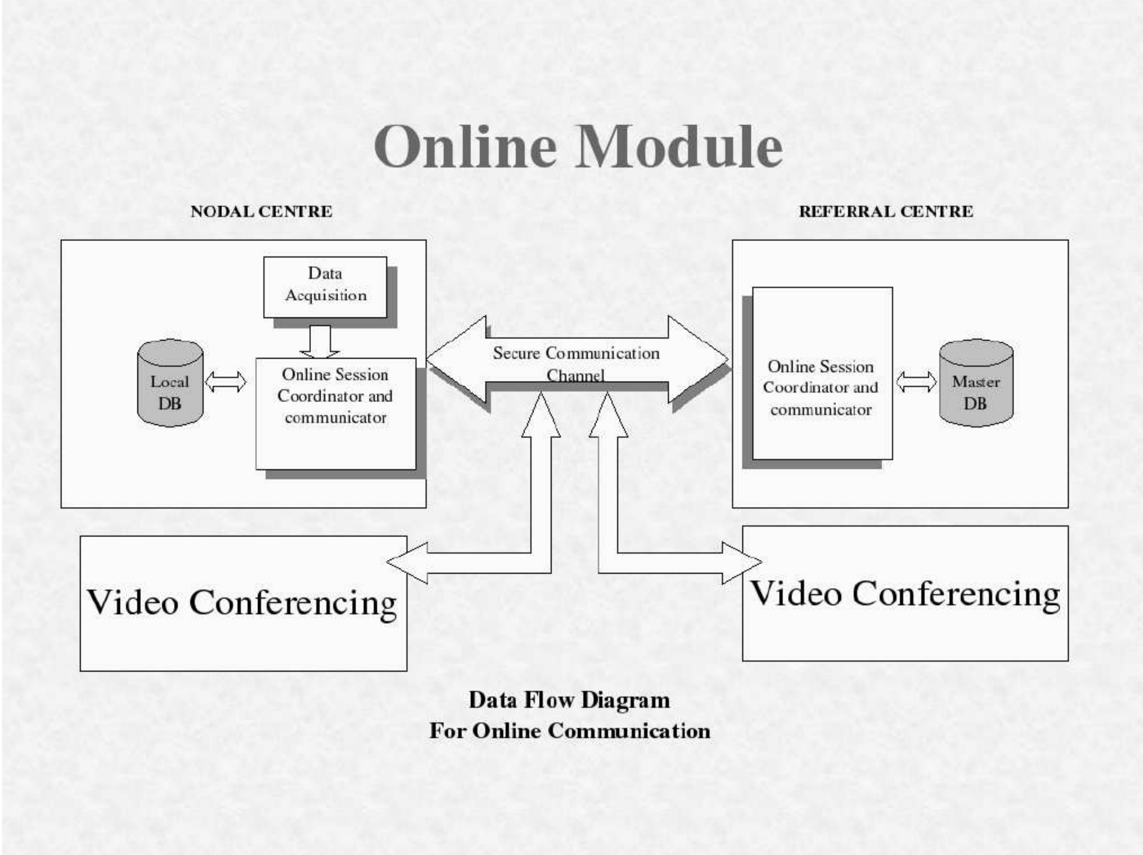


Figure 6: On-line Operations

patient queue, scheduling a session, data archival etc.

5.5 On-line Operations

A schematic diagram of the on-line operations is given in Fig. 6. Provision for data acquisition is also kept during this operation. On-line operations are performed with a single graphical users' interface (GUI). Its different functionalities are decribed below:

1. **Session Coordination** : Telemicine sessions are intiated by establishing a connection between two ends. Data communication takes place using chat boxes (for text) and graphical canvases (for graphics and images). A list of patients, scheduled for the telemedicine session (for that day) is displayed in a session. The physicians are expected to select them one by one and perform the telemedicine operation.

   At the end of a patient's telemedicine, the patient data is automatically backed up in the data base (updating visit information in the referral end and the forms and all other information at the nodal end). The files in the working directory are also removed (options being asked at the both end) at the end of the session. The patient queue also records the completion of a telemedicine for a patient and optionally asks for its removal from the queue.

2. **Data Conferencing**: During data conferencing, two ends communicate by sending text and graphics primitives. The interface provides a common canvas for conferencing with graphic

primitives (i.e. by drawing, annotating etc.) with the patient data. As the same patient data is available at the both end, the actual bandwidth requirement is very small. This kind of conferencing is possible with the various backgrounds such as white background or white board, a medical test image, special images such as human profiles etc. The module supports conferencing with multiple canvases (presently four in our implementation). Operations such as drawing lines, contours, circles, ellipses, text annotations etc. are provided. Some image processing operations such as zooming of a portion of image, edge extraction, enhancement etc. are also supported. The colors of the graphics primitives identify different centers. The module also has its own a small chat box.

3. **Image Communication**: During on-line data conferencing one may also send a new image from the nodal end to the referral end. As the transfer of image data in low speed communication link takes considerable time, an interactive protocol for sending multi-resolution images has been designed.

4. **Form Communicaton**: A new form (structured text) containing patient's history, pathological test reports etc., could be sent as and when required. It may be noted that from the referral end, the prescriptions are also sent by the expert physician using form communicator.

5. **Video and audio conferencing**: Given a higher bandwidth channel (such as ISDN, 2 Mbps leased line etc.), commercially available video conferencing software (using Microsoft Netmeeting^{TM}) is used for on-line video conferencing. However, for a low bandwidth link (say POTS), it has been found that these softwares are not able to function at all. Hence we provided an alternative solution for the telephone lines. In this case, we transfer the frames at a very slow rate (say a frame per 15 seconds) and display it at the other end. We have used JPEG compression for compressing these frames. This enables the physicians to see each other (including the patient) and simple gestures could also be communicated. The audio in this case is handled independently using an extra telephone line.

5.6 Trials and Deployments

Several experimental trials have been carried out between different places (specially between Kharagpur and Calcutta, separated at a distance of 116 Km). In our experimentations, we have used both the ISDN links and telephone lines in the busy hour (between 11 AM to 2 PM) of a working day. Also, inhouse testing over LAN has been performed. In the experimentations, fictitous patient data, test reports, images and leprosy patches are captured at the nodal end (Kharagpur in our case). The data were organized, distributed and sent to the referral end (Calcutta). At the referral end, the data had been browsed and after that on-line telemedcine sessions have been carried out. In the case of ISDN (and also LAN) links, video (and audio) conferencing was simultaneously performed with the data conferencing using Microsoft Netmeeting^{TM} and Webcam^{TM} cameras. It has been observed on ordinary telephone lines, these software could not function, as the data rate drops below 10 Kbps in the most of the time. Hence we used slow video transfer module, which could function even at 9 Kbps data rate without any trouble.

The system has been presently deployed in West Bengal (Fig. 7) for the treatment of tropical diseases. The deployment is being carried out by Webel, West Bengal. The School of Tropical Medicine, Calcutta is acting as the referral center. One of the nodal centers are situated at Habra State General Hospital at North 24 Parganas, which is roughly at a distance of 50 Km. from Calcutta. The system is operational since February, 2002. Two months later another nodal center at Kuchbihar District Hospital (roughly at a distance of 500 Km from Kolkata) has been set up.

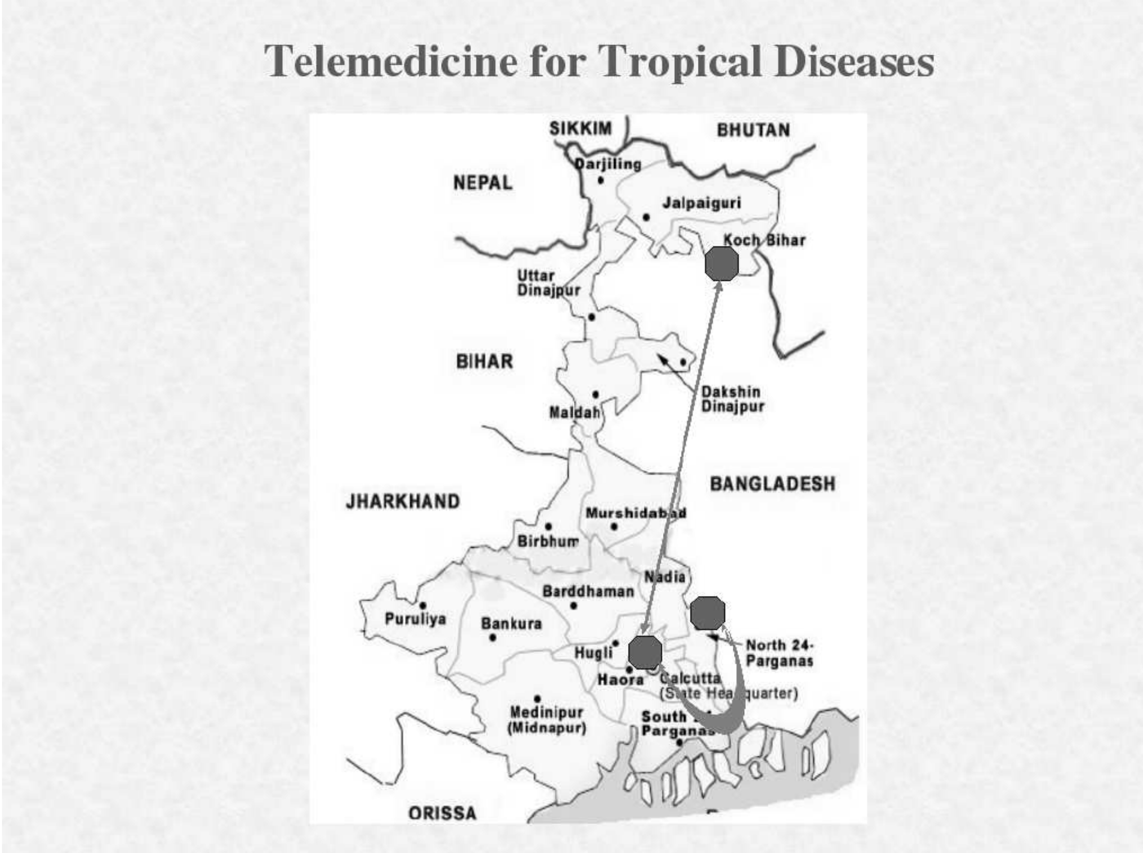


Figure 7: Telemedicine for tropical diseases

More than 900 patients have been treated in one year in these centers. Initially the system was operated using two telephone lines, one for data conferencing and the other for normal telephone conversation. In this year, the communication link has been enhanced by ISDN lines. Another project connecting six hospitals of West Bengal for the purpose of teleradiology (Fig. 8) is currently being taken up. It is expected to be completed by the end of this year.

6 Conclusion

Telemdicine is referred to the diagnosis and treatment of patients from a remote place, where the patient is not physically present. Usually, in a telemedicine system, two physicians at two ends consult with each other with the patient data. It is the result of convergence of different technologies, namely *medical instrumentation*, *information technology,* and *telecommunication technolgy.* Though telemedicine was being practiced at different sectors of advanced industrial countries since the beginning of the twentieth century, it was not widely used as the technology was not cost-effective and also unable to provide the necessary infrastructure for its deployment. Due to the revolution in the digital computing and communication technology in the last decade of the past century, telemedicine is getting more and more acceptances in health care sectors. At IIT Kharagpur, a telemedicine system has been developed which is both cost effective and scalable for its uses in various sectors. Presently, the system is being used in the public health sector of West Bengal.

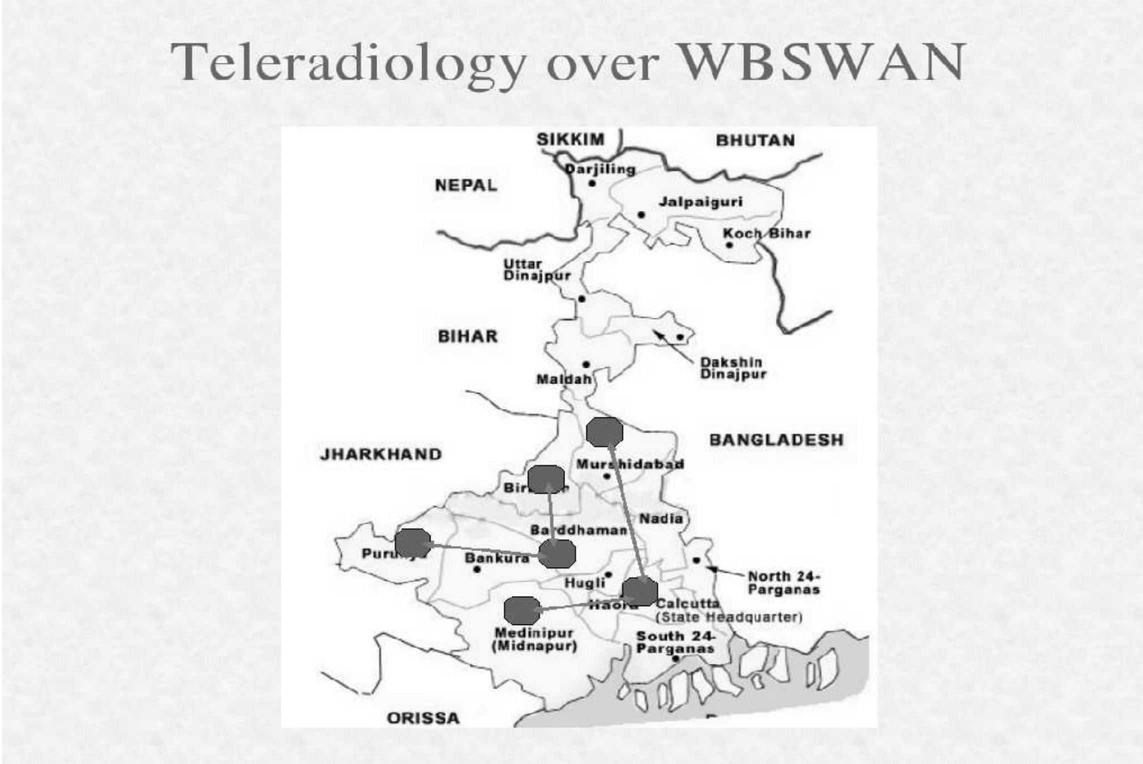


Figure 8: Proposed telemedicine network for radiology

Acknowledgement

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