COMMUNICATION NETWORK FOR TELEMEDICINE

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ABSTRACT

Telemedicine is the most promising one for improving the access to specialized health services to all remote, rural areas in all developing countries. Exploiting the technological advancements in the field of electronics, signal processing and software a communication network for telemedicine is proposed for the existing twisted pair based public switched public data network. To expand the bandwidth capability of twisted pair network to gain the near capability of optical fiber based Broadband Integrated System Digital Network BISDN), additional subsystems High-Bit-Rate Digital Subscriber Line (HDSL), Asymmetric Digital Subscriber Line (ADSL) and the advanced modulation techniques for bandwidth compression are discussed. A complete communication network for delivering telemedicine to all the developing countries is presented.

INTRODUCTION

Telemedicine is the need of the hour for all developing countries. It is a well-known fact that medical care and treatment available to third world countries is very much limited for a number of reasons. Telemedicine, an electronic communication networks that connects different health center spread over the country. It has several advantages such as travel time, specialist advice, consultation, cost etc. The major focus of telemedicine research and pilot programs continues to be improving quality of medical care in under served rural areas.

Telemedicine encompasses four major components viz. (1) Diagnostic and consultative support to the medical practitioner in the remote area. (2) Direct delivery of medical care to patients at distant sites (3) continuing medical education and (4) Training the medical practitioners under experts supervision [1,4,5]. Since the introduction of Integrated Services Digital Network (ISDN) in the early 1980s, the communication network is growing rapidly. Today higher bandwidth such as teleconferencing, cable TV, high definition TV etc. are included in addition to narrowband ISDN services such as voice, facsimile, computer data etc. The application of advanced telecommunication technology to the delivery of medical care in particular to under developed countries is discussed in this paper.

In the following consecutive sections of this paper different issues of telemedicine has been covered. Section II of the paper, deals with the basic subsystems of telemedicine and addresses the representative platforms of telemedicine with their respective structures. It also discusses the role-played and limitations encountered in each platform. How the existing infrastructure in developing countries looks like is dealt in section III. Here an attempt has been made to determine what is available and what is not. In section IV improvements required in the infrastructure and network is addressed. Finally, the conclusion drawn from this exercise is presented in section V.

TELEMEDICINE

The telemedicine system should support various medical disciplines and consultation functions to collaboratively transfer, manipulate, and view radiological images, image sequences, clinical, non-clinical tests, audio, and video. Accordingly a Telemedicine system consists of at least five major subsystems [1,4]. They are audio, video, conferencing, high-resolution/luminosity and medical information subsystems.

i) AUDIO
It is used for voice communications between the remote health care center and the central service provider. It encompasses microphones, speakers, echo-canceller and noise reduction units.

ii) VIDEO
This is used for viewing remote participants and sharing documents. Monitors, camera and visualizer (document camera) are the basic components of the video subsystem.

iii) CONFERENCING
This subsystem is essential for establishing and maintaining network connections. It can include phone; Integrated services digital network (ISDN), local area network (LAN) and asynchronous transfer mode (ATM) networking.

iv) HIGH-RESOLUTION/LUMINOSITY
It is necessary for extremely high quality needs both in spatially and temporally (e.g. Large X-rays or echo cardiograms) which require tremendous bandwidth in real-time. This subsystem manages remote capture of images or video for off-line transmission and review.

v) MEDICAL INFORMATION
This is the subsystem used for interfacing to clinical databases to store information created or captured during teleconsultations as patient records.

Communication Model to Telemedicine

A simplified graphic representation of the communication model [4] for telemedicine is given in Fig. 1.

The clinical level of the model is meant to encompass the full spectrum of telemedicine concepts, e.g., teleconsultation, telementoring, telepresence and telemonitoring as well as the application of these concepts across the field of specialty and subspecialty medicine and the range of medical practitioners (e.g., physician, nurse, physician's assistant).

To support distance independent clinical practice a variety of communications applications are required. Although the predominant application today is video teleconferencing (VTC), image transport, remote sensors, and access to a distributed electronic patient record are also critically important.

An extensive and rapidly growing suite of wireless and wire-line (optical network) telecommunication facilities provide the basis for telemedicine applications. The selection of services at this lowest level of the model is determined by availability, cost, and an array of application specific requirements such as mobility, security, power consumption, ruggedness of transmission equipment, etc. For example, with the advent of global cellular networks, the same equipment could be used to monitor the vital signs of an elderly patient in one remote area or a soldier on the battlefield. Network Protocols such as Transport Control Protocol/ Internet Protocol (TCP/IP) provide the all-important glue that binds user applications to the telecommunication infrastructure. Connectivity is dependent on the choice protocol. Certain application domains may have specialized standard protocols by adding domain specific functions that enhance the value of the base protocol. Such is the case with the Digital Imaging and Communications in Medicine (DICOM) standard, which adds specific functionality for medical image communication and management to TCP/IP.

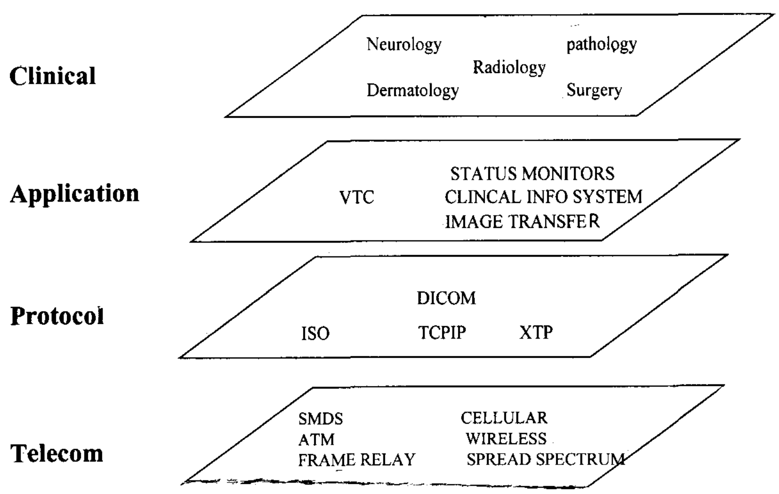


Figure 1 Communication Model of TeleMedicine

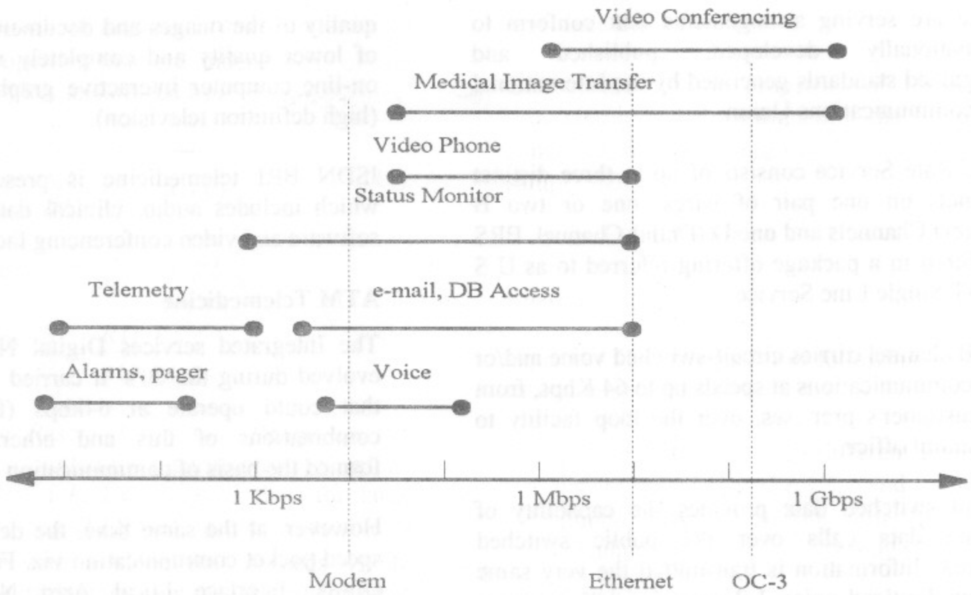


Figure 2 Bandwidth requirement of Telemedicine related application (Bits per second)

DICOM is an application layer network protocol [2] for the transmission of medical images, waveforms, and ancillary information. It was originally developed by the National Electrical Manufacturers Association (NEMA) and the American College of Radiology for CAT and MRI scan images. It is now controlled by the DICOM Standards Committee, and supports a wide range of medical images across the fields of radiology, cardiology, pathology and dentistry. DICOM uses TCP/IP as the lower-layer transport protocol.

Fig. 2 depicts the various bandwidth requirements for telemedicine application.

ISDN Telemedicine

Integrated Services Digital Network, or ISDN, is a digital architecture that provides an integrated voice/data capability to the customer premises facility, utilizing the public switched network [5]. ISDN distributes voice, data, video, image and facsimile by two standard methods of access: Basic Rate Service (BRS) or Primary Rate Service (PRS).

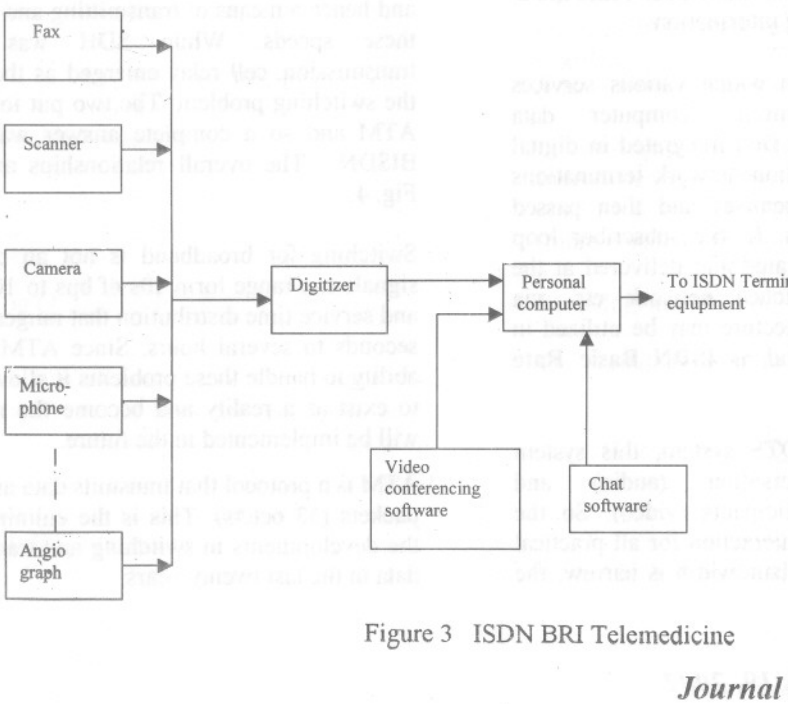


Figure 3 ISDN BRI Telemedicine

These are serving arrangements that conform to internationally developed, published and recognized standards generated by the International Telecommunications Union.

Basic Rate Service consists of up to three distinct channels on one pair of wires: one or two B (Bearer) Channels and one D (Delta) Channel. BRS is offered in a package offering referred to as U S WEST Single Line Service.

The B channel carries circuit-switched voice and/or data communications at speeds up to 64 Kbps, from the customer's premises, over the loop facility to the central office.

Circuit switched data provides the capability of making data calls over the public switched network. Information is transmitted the very same way as digitized voice. Like a voice call, a circuit switched data call ties up the network/system resources for the duration of the call. Similar to voice, Calling Line Identification is provided.

The D channel carries signaling packet data information, at speeds up to 16 Kbps on BRS and signaling only information up to 64 Kbps for PRS, from the customer's premises to the central office. The D channel has both data and signaling functionality; it does not have voice capability.

PRS has a capacity of 1.544 megabits per second and has multiple channels: 23B channels and one D channel (23B + D). The B channels carry voice calls, circuit switched data, and video, while the D channel handles signaling information.

ISDN has a structure in which various services (telephone, fax, facsimile, computer data communication, text) are first integrated in digital mode at the communication network terminations inside the subscriber premises and then passed through subscriber loops. In the subscriber loop these messages are separated and delivered at the appropriate circuit switched network etc. via central office. This architecture may be utilized in total for telemedicine and as **ISDN Basic Rate Interface telemedicine**.

As compared to the POTS system, this system provides both conversation (audio) and visualization of the participants (video). So the system is closer to real interaction for all practical purposes. But since the bandwidth is narrow, the quality of the images and documents transferred is of lower quality and completely not meeting the on-line computer interactive graphic transmission (high definition television).

ISDN BRI telemedicine is presented in Fig.3, which includes audio, clinical data scanner, chat software and video conferencing facilities.

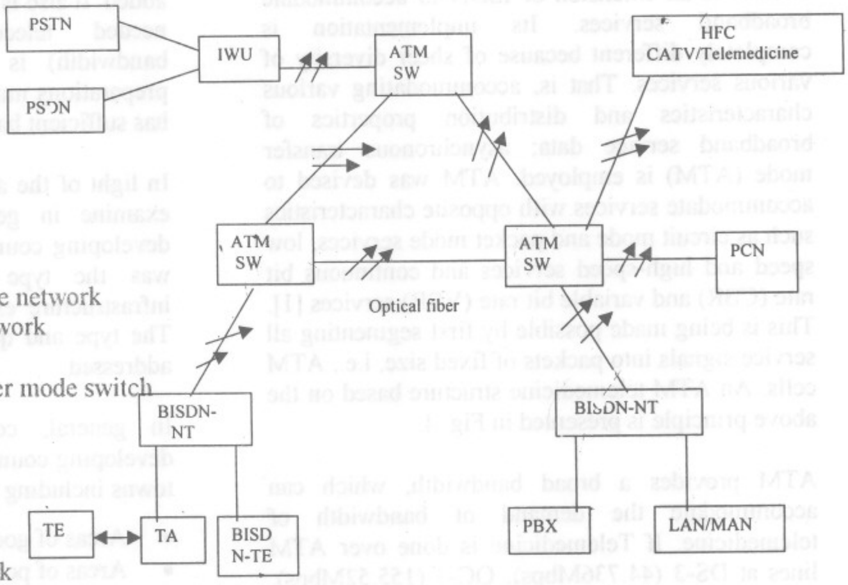
ATM Telemedicine

The Integrated services Digital Network (ISDN) evolved during the 80's. It carried a basic channel that could operate at 64kbps (B-channel) and combinations of this and others (D-channels) formed the basis of communication on the network.

However, at the same time, the demand for high-speed packet communication viz. Fiber Distributed Digital Interface Local Area Network (FDDI LAN), Distributed Queue Dual Bus Metropolitan Area Network (DQDB MAN) and video communication (developments in gigabit networks-ATM) increased. For video, opticalizing the CATV networks and desire for videophones and video conferencing has led to the need for high-speed and broadband services. Further, Broadband-ISDN was created which conceptually is just an extension of ISDN so it functions as a communication network that can provide integrated broadband services such as high-speed-data service, video phone, video conferencing, CATV services along with traditional ISDN services such as phone and telex. This diversity of service meant transmission speeds in the region of 155Mbps, 622Mbps and 2.4Gbps, and hence a means of transmitting and switching at these speeds. While SDH was used for transmission, cell relay emerged as the solution to the switching problem. The two put together made ATM and so a complete answer was found for BISDN. The overall relationships are shown in Fig. 4.

Switching for broadband is not an easy task as signals can range form 10s of bps to 100s of Mbps and service time distribution that ranges from a few seconds to several hours. Since ATM [3] has the ability to handle these problems it allowed B-ISDN to exist as a reality and become the network that will be implemented in the future.

ATM is a protocol that transmits data as fixed sized packets (53 octets). This is the culmination of all the developments in switching and transmission of data in the last twenty years.



PSTN: Public switched telephone network
PSDN: Public switched data network
IWU: Interworking unit
ATM SW: Asynchronous transfer mode switch
NT: Network termination
TE: Terminal equipment
TA: Terminal adapter
PBX: Private branch exchange
LAN: Local area network
MAN: Metropolitan area network
PCN: Personal communication network
HFC: Hybrid fiber cable
CATV: Cable television

Figure 4 Architecture of BISDN

It was designed to make Broadband-ISDN (B-ISDN) a reality. B-ISDN was created conceptually as just an extension of ISDN so it functions as a communication network that can provide integrated broadband services such as high-speed-data service, video phone, video conferencing, CATV services along with traditional ISDN services such as phone and telex.

To have the B-ISDN services mentioned above an interface between the ATM layer and higher layers was necessary. The ATM adaptation layer provides this service. Its main purpose is to resolve any disparity between services required by the user and services available at the ATM layer. It lies between the ATM layer and the higher layers of the B-ISDN protocol reference model.

The ATM cell is the basic unit consisting of payload and header. The cell is comprised of 53 bytes. Five of the bytes make up the header field and the remaining 48 bytes form the user information field.

ATM cells are transported via virtual channels and indirectly in virtual paths. A virtual channel is a unidirectional pipe. A virtual path is made from of a set of these channels.

The ATM cells traveling through the virtual pipes and channels will need a physical medium (e.g. fiber optic cable) for network. The physical layer, its essential purpose is to collect and organize ATM cells sent down from the ATM layer, transport them to the physical medium and also perform the reverse of the process.

An ATM network needs certain traffic control capabilities to deal with applications such as video conferencing. It needs a guaranteed amount of bandwidth made available for the communications link while still using the network as efficiently as possible and to cope with potential errors within the network at any time (e.g. a problem with the physical layer).

ISDN being 64 kbps, it could not meet the demand of high-speed packet (computer graphics) and video (high definition television) communication services. Hence it is out of necessity and communication technological evolution that has given birth to broadband ISDN (BISDN), though BISDN is an extension of ISDN to accommodate broadband services. Its implementation is completely different because of sheer diversity of various services. That is, accommodating various characteristics and distribution properties of broadband service data; asynchronous transfer mode (ATM) is employed. ATM was devised to accommodate services with opposite characteristics such as circuit mode and packet mode services, low speed and high-speed services and continuous bit rate (CBR) and variable bit rate (VBR) services [1]. This is being made possible by first segmenting all service signals into packets of fixed size, i.e., ATM cells. An ATM telemedicine structure based on the above principle is presented in Fig. 4.

ATM provides a broad bandwidth, which can accommodate the demand of bandwidth of telemedicine. If Telemedicine is done over ATM lines at DS-3 (44.736Mbps), OC-3 (155.52Mbps), or OC-12 (622.08Mbps), a workstation-based system makes a great deal of sense due to the ability to distribute the hardware to where it is needed.

All applications and features listed above in the two systems (CBR & VBR) should be possible at optimal resolutions and levels of functionality with ATM Telemedicine. Additionally, Pediatric Echo-cardiology, angio graph, etc. should also be included.

Coming to the infrastructure facility ATM telemedicine is a fiber based communication network up to the drop, and is not available in many of the developing country. Further it is a very expensive system, which normally no developing country can afford to invest such a huge chunk of money. Hence it is worthwhile to investigate a telemedicine system that makes use of the available communication infrastructure. To this end one need to take a stock of the situation about the availability.

EXISTING INFRASTRUCTURE

Before proceeding to upgrade, there should be a careful inventory of available telecommunications capabilities and equipments in developing countries. The inventory could give an idea of the technology and how much of the existing equipments could be used for the telemedicine system. This is the starting point to assess what additional subsystems/ or equipments need to be added. It also is necessary to determine whether the needed telecommunications capacity (e.g., bandwidth) is available to each site. If not, preparations must be made to assure that each site has sufficient bandwidth.

In light of the above, attempts have been made to examine in general the available resource of developing countries. The main focus of attention was the type and condition of the current infrastructure existing in the towns and villages. The type and quality of service was also broadly addressed.

In general, considering the infrastructure of developing countries we can broadly categorize the towns including the villages into three. That is,

- Areas of good infrastructure
- Areas of poor infrastructure
- Areas with no infrastructure

The current telephone service in developing countries naturally reflects the available infrastructure and may also be put in three categories.

- Areas of fairly good telephone service
- Areas of poor telephone service
- Areas without any telephone service

In light of modern Internet service, the areas in any developing country may fall in any of these two categories.

- Areas with fairly good Internet service
- Areas without Internet service

Now, summarizing the existing telecom structure it does avail both analog and digital switching technology. All the trunk lines are fairly well established and maintained. The trunk lines are either connected with microwave link or satellite. Hence it is capable of handling the data rate starting from 64kbps (voice) to 1Gbps (high definition TV). The subscriber network, which constitutes a portion that links telephone office and the subscriber is a copper based twisted pair wire. Hence it has limited bandwidth and transmission distance. The communication modes are both analog and digital. The transmission hierarchy at present is analog and plesiochronous digital hierarchy (PDH) with synchronous digital hierarchy (SDH) at the introduction stage.

TWISTED PAIR BASED BANDWIDTH EXPANSION

The main concern here is that how to make the existing telecommunication infrastructure to up grade for the delivery of telemedicine. To this end the services are to be provided should be a fully interactive, voice and video and also full duplex data to transfer patients records and examination data.

ADSL

Asymmetric Digital Subscriber Line (ADSL) takes its name from the comparatively high bandwidth downstream, with low bandwidth upstream. ADSL can achieve data transmission at speeds between 1.5Mbps and 8Mbps over a single copper pair specifying loops up to 18,000ft at a wire thickness of 0.5mm (24 gauge).

An ADSL circuit connects ADSL modems on each end of a twisted-pair telephone line, creating three information channels: a high speed downstream channel ranges from 1.5 to 8 Mbps, a medium speed duplex channel ranges from 16 to 640 Kbps and a POTS (Plain old telephone service) channel. The POTS channel is split off from the digital modem by filters, thus guaranteeing uninterrupted POTS, even if ADSL fails.

available too. Downstream data rates depend on number of factors, including the length of the copper line; it's wire gauge, presence of bridged tapes and cross-coupled interference. Line attenuation increases with line length and frequency, and decreases as wire diameter increases. Ignoring bridged taps, ADSL will perform as given in Table 1.

Table 1:

Data Rate In Mbps	Gauge (AWG)	Diameter in mm	Distance in km
1.5 or 2	24	0.5	5.5
1.5 or 2	26	0.4	4.6
6.1	24	0.5	3.7
6.1	26	0.4	2.7

Premises beyond these distances can be reached with fiber based digital loop carrier systems.

A movie quality video and audio signal can be supported with 6.312 megabytes per second (Mbps) up to 8.448 Mbps rate digital link. To provide this link between telecom offices and the telemedicine service provider studio or between a remote telecom station and the primary health care center (drop in this case), two pairs of asynchronous digital subscriber line (ADSL) can be used as shown in Fig. 5 using 24 gauge twisted-pair (TP) wires. The bandwidth of the twisted pair based subscriber line significantly increased further with ADSL unit at both ends of the TP wire that modulates and demodulates the information for transmission and reception.

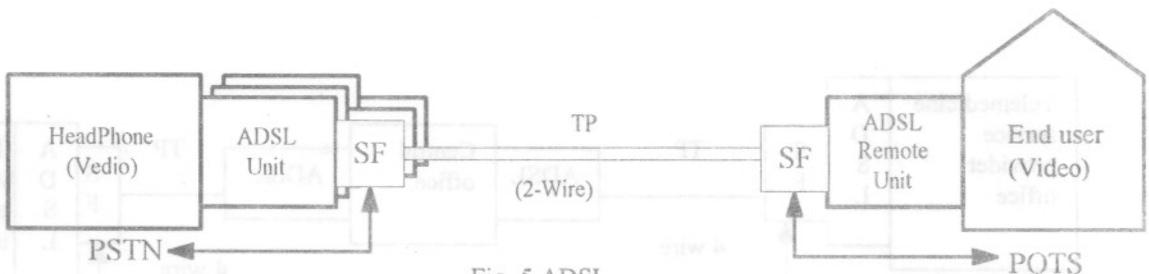


Fig. 5 ADSL

ADSL modems are available off the shelf and can be purchased with various speed range and capabilities. The minimum configuration provides 1.5 or 2 Mbps downstream and 16 Kbps duplex channel; other provides rates of 6.1 Mbps and 64 Kbps duplex. Products with downstream rates up to 9 Mbps and duplex rates up to 640 Kbps are

HDSL

High-Bit-Rate Digital Subscriber Line (HDSL) was developed in the early 90s as an alternative way to achieve T1 (North American) and E1 (European) speeds (1.5 to 2.0 Mbps). The idea was to apply the same line coding (2B1Q) technique as was used in

ISDN, split the service on two phone lines (four wires), increase the data rate and reduce the frequency spectrum needed.

bridged taps it significantly simplifies the labor and engineering effort to support the service. It also reduces the time, cost, and effort of isolating faults and taking corrective action when a failure does occur.

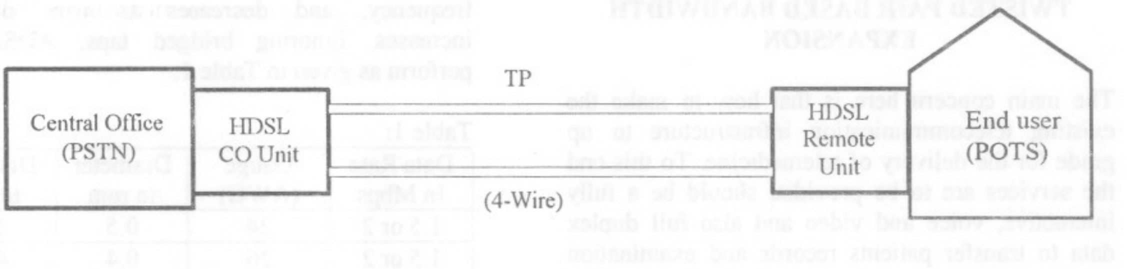


Fig. 6 HDSL

The result was an HDSL-based service, specifying loops of up to 12,000ft at a wire thickness of 0.5mm (24 gauge). Subsequently, another line coding technique called Carrier less Amplitude Phase modulation (CAP) was introduced which enabled the use of an even lower range of the frequency spectrum, with less attenuation and longer loop reach. Both ANSI and ETSI's (the American and European standards bodies) HDSL standards committees have endorsed these line codes in technical reports.

The main characteristic of HDSL is that it is symmetrical (an equal amount of bandwidth is available upstream and downstream). HDSL has proven to be a reliable and cost effective means for providing repeater-less T1 and E1 services over two copper pair loops. As HDSL eliminates the need for repeater equipment and the removal of

To transfer data to and from the remote telemedicine stations either 1.544 Mbps (North American) or 2.048 Mbps (European) information link could be sufficient. Such links could be provided on 24 gauge twisted pairs by using high-speed digital subscriber lines (HDSLs) on four wires as shown in Fig. 6.

The required numbers of ADSL and HDSL shall be determined based on the number of remote stations required to be linked to the service provider. If the service grows and number of remote customers increase significantly the link between the central microwave station and the service provider will be upgraded to optical fiber.

Figure 7 reflects the broadband ISDN requirements with the drop being TPs.

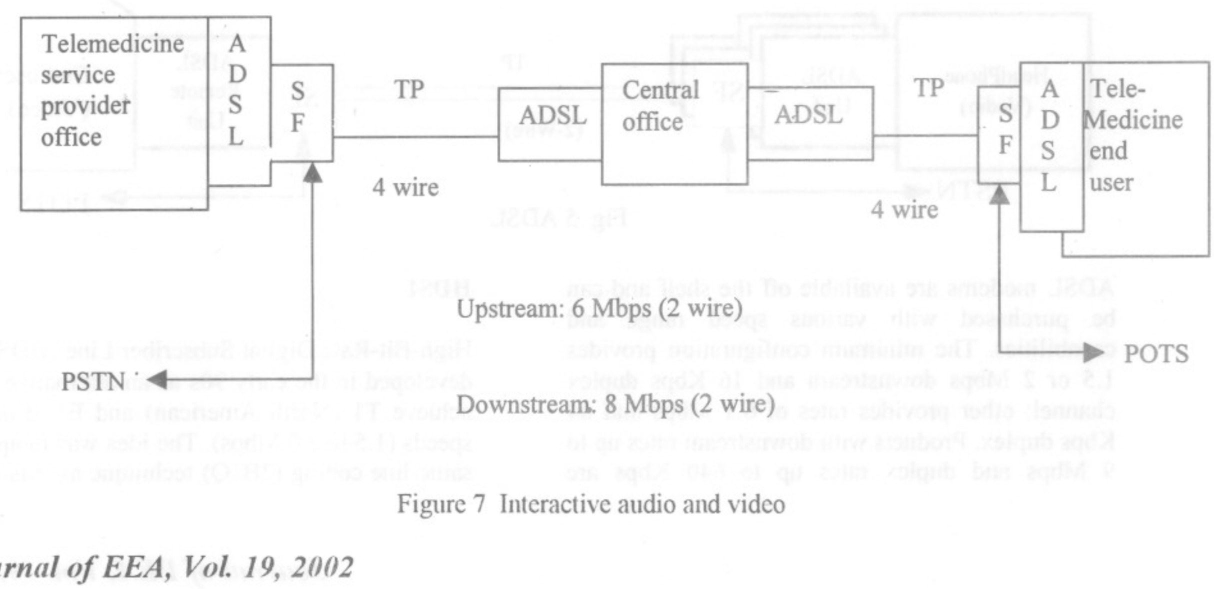


Figure 7 Interactive audio and video

Modulation Technique

There are two main modulation methods that can be used with the DSLs for bandwidth compression. They are:

(i) Discrete Multi-Tone modulation (DMT)
(ii) Carrier less Amplitude modulation and Phase modulation (CAP).

Discrete MultiTone (DMT)

Copper lines have a frequency spectrum of 1.1MHz, which can be used to data communication under two main limitations:

1. The POTS are using the lower 4KHz.

2. The amplification is not the same in all frequencies.

The technology being used is DMT that divides the frequency rang to 256 sub-frequencies (sub channel) starting from 64KHz to 1.1MHz. The sub channels are encoded to the corresponding N quadrature amplitude modulation (QAM) (n = 16/64/128/256). Collection of N QAM symbols is modulated through IDFT as shown in Fig. 8.

Each sub-frequency is an independent channel and has its own stream of signals. The ADSL protocol defines a basic stream of data that is known to both end points in advanced and enables them to find the specific SNR for each sub-frequency, and uses this information to split the data over the sub-frequencies.

It is important that the ADSL will not affect the POTS in any way, to accomplish that the lower 4Kbps is separated by a analog circuit called Splitter .In this way one can make simple phone calls and use ADSL services in the same time.

The DMT technology is also very useful in the asymmetric mode where the sub-channels are divided to groups, one for the upstream data (from the endpoint to the PTT) and the other for the downstream data (from the PTT to the end user)

CAP

CAP transceiver structure is given in Fig. 9. It is a two-dimensional pass band modulation derived from quadrature amplitude modulation (QAM). It is less complex to implement. Its characteristics and performances are same as that of QAM. The input to the encoder is segmented into blocks of 'm' bits and multi dimensional encoding is carried out on the input data stream.

CAP algorithm gives the data bit combinations a form of both Amplitude and phase and in this way creates a number of signals to be sending over the Twisted pair lines. Unlike the DMT, CAP uses the whole frequency range from 4KHz up to 1.1MHz as one channel. CAP is used today in some of the modem communication standards like V.32/V.32bis.

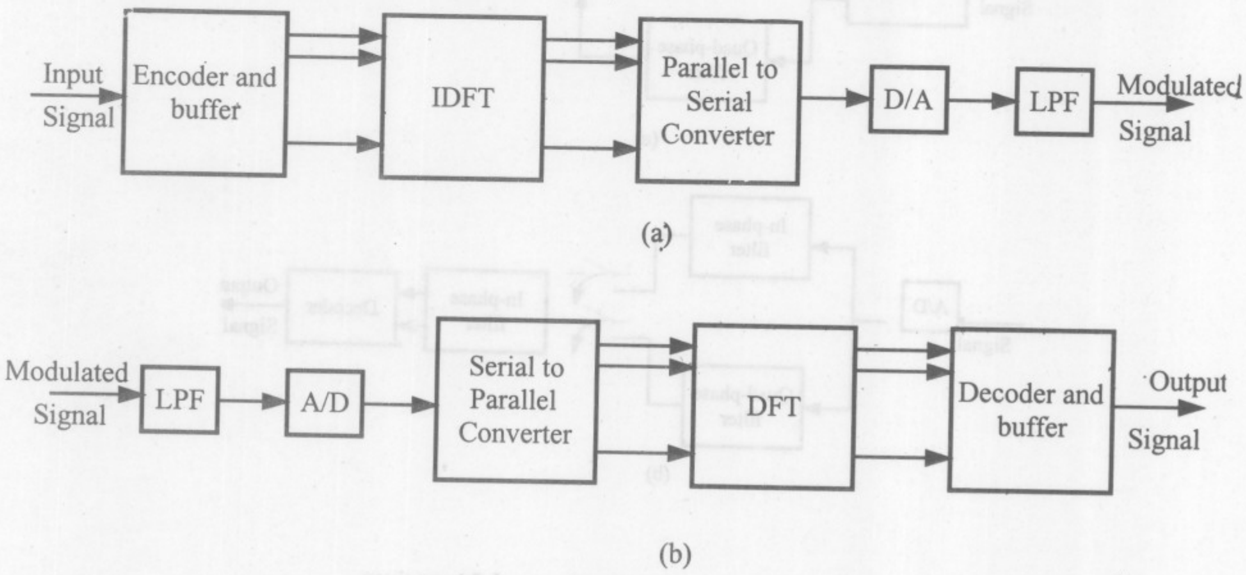


Figure 8 DMT transceiver structure: (a) transmitter (b) receiver

The number of signals that the CAP can generate depends on the amount of information bits one want to send over the line, by using different encoder CAP can adjust the bit rate (data compression) of the ADSL session in real-time.

Main advantages of CAP are:

- Lower cost
- Lower latency
- Rate adaptivty

On the other hand DMT is considered a more reliable and sophisticated technology and it is likely to dominate the future communication world.

CAP and DMT use a lower range of frequency spectrum than the earlier alternative line coding techniques. They have reduced signal attenuation and enabled desired loop reach to be achieved. That is why CAP and DMT have become the most popular line coding techniques to be used to support DSL technology.

The main difference between these two line-coding methods is in determining the optimum speed between the central office and the service user over a single copper pair. CAP treats the entire frequency spectrum as a single channel and optimizes the data rate while DMT divides it into 256 sub-channels and optimizes the data rate for each sub-channel. CAP has been tested longer than DMT, but DMT has been accepted as the standard by ANSI and ETSI.

The ITU/TSS ADSL standard defines the DMT as the modulation method to be used in ADSL communication equipment but some of the manufacturers are working on a different standard that will use the CAP technology

Figure 10 shows the overall telemedicine network depicted between the service provider, and primary health center by utilizing satellite/microwave link. Here all the five major subsystems required for telemedicine are included since the telecom network is catered for both broadband and narrow band signals.

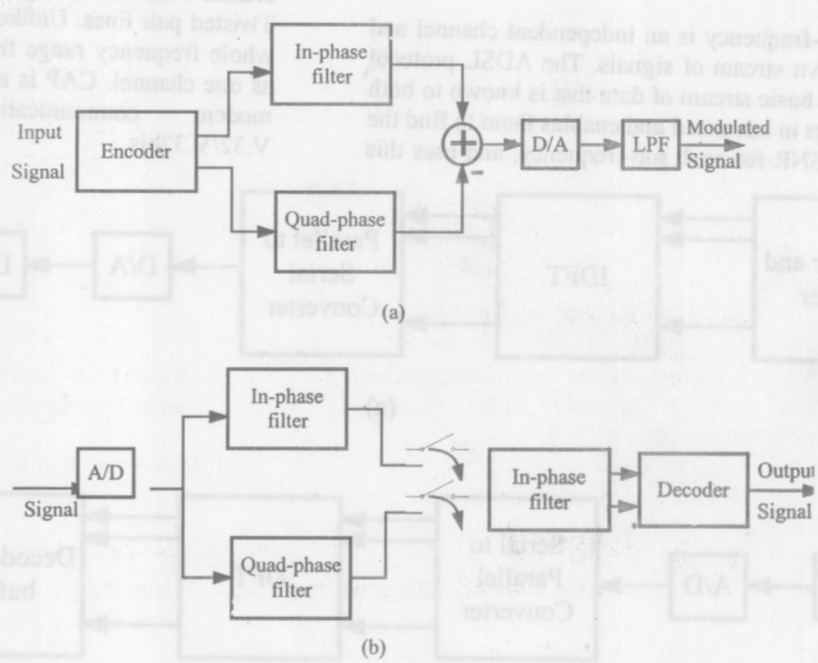


Figure 9 CAP transceiver structure: (a) transmitter and (b) receiver

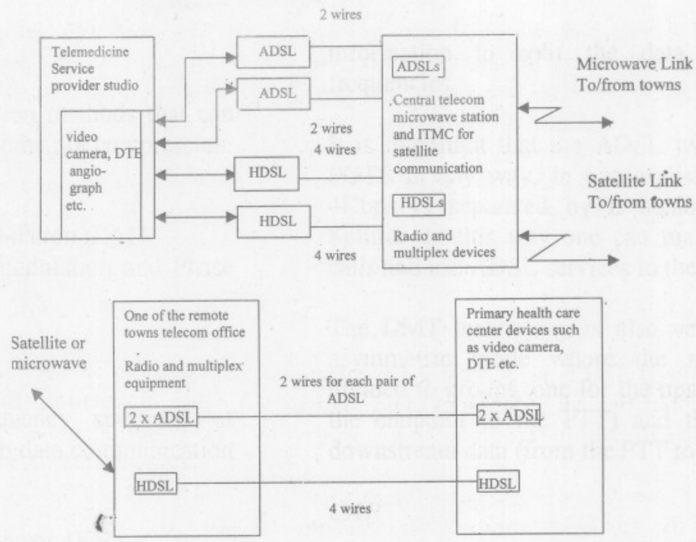


Figure 10 Telemedicine service on existing network

CONCLUSION

Utilizing the advanced modern telecommunications technology, communities have immediate access to a world of services. As a part of this, telemedicine holds much promise for improving access to health services in rural, underserved communities. Developing countries should come forward to reap the benefits from modern telecommunication technology. The upgrading suggested and many of the principles outlined in building the telemedicine network should be useful for any town or village contemplating development of telemedicine service. The most essential step to be done to deliver the service broadly is to upgrade the existing infrastructure to reliable digital network that makes the application of BISDN possible throughout the developing countries.

Hence, by developing the appropriate technology and tools in co-operation with trained health-care personnel, it is clear that great improvements in the delivery of medical services to rural and remote areas can be made.

That is not to say that challenges do not exist, however! There are several barriers inherent in overcoming distance in delivering health care-technological and professional. Among them the most challenging is infrastructure planning and development. It is unusual for health-care applications to be considered in planning and developing new telecommunications and information technology. While this challenge is difficult, it can be overcome with cooperation among health-care professionals, technology specialists, and governments. Such cooperation is the key to telemedicine's achieving its potential to improve health care. Finally, concluding by saying that health is the wealth of any country, the country can progress in all fields by providing good health care to all citizens, with the effective utilization of limited available resources and infrastructure in this regard.

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