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# Medical image communication systems

José M. Costa

New Services Planning, Bell-Northern Research Ltd.  
P.O. Box 3511, Station 'C', Ottawa, Canada K1Y 4H7

## Abstract

This paper discusses the feasibility of an integral communications system to include images for medical applications, for both intra-hospital communications and networking to remote locations and systems. Emphasis is placed on image communications because they will become an important component of telecommunications traffic in the 1980's if the proper facilities are provided. Terminals distributed throughout a hospital and in remote locations could access the databases of images and medical reports. Radiologists could prepare the medical diagnosis reports much faster, shortly after the radiograph was taken, by examining the radiographs on a suitable soft-copy display and dictating the report, ultimately using automated voice recognition systems. To lower the cost of the system the expensive hardware could be shared by means of communications, so that their utilization is maximized. Several configurations are proposed in this paper and their relative cost/performance compared. System evolution is also considered.

## Introduction

Medical imaging has generally been based on film. Since film is slow, expensive and cumbersome to handle, several institutions and laboratories have investigated the use of electronic imaging systems (e.g. [1], [2], [3], [4]). Their purpose is to complement or replace film for improved diagnosis, and to enable users to work with more cost-effective systems. Those who have used electronic imaging systems have been constrained to stand-alone systems or the use of television technology or slow-scan TV for communications and networking. Today, high speed digital networks are possible, using new technologies such as fibre optics and satellites. However, before public wideband networks can be used the local (in-building or intra-hospital) needs will have to be satisfied first. Economic advantages are gained if all communication needs are integrated into the same system. Traditionally, the PBX (Private Branch Exchange) and the PSTN (Public Switched Telephone Network) have been the vehicles for in-house and networking, respectively, of voice and low-speed data communications. However, these systems must evolve; most of today's networks were not designed to transmit large volumes of data in a short time, as would be required, for example, for medical images. Since the need to transmit medical images fast, and at low cost, is becoming more and more pressing, it is postulated here that this will be one of the driving forces which will encourage the growth of wideband communication facilities.

The objective of this paper is to present work-in-progress on medical imaging from the viewpoint of communications, and to encourage discussion to understand better the real needs. The paper starts with a justification and general description of Medical Image Communications Systems (MICS) and considers the key requirements and technical issues. The alternatives for refreshing multiple CRT displays are considered in more detail because communications allow for resource sharing and the system can be configured in a cost-effective way. Finally, a view of a possible evolution of medical image communication systems is presented.

## Technical issues leading to imaging systems

An integral communication system will have to satisfy all communications needs, which in the case of medical institutions include communications of:

<u>Type of signal</u>	<u>Examples of Applications</u>
voice	person-to-person, conferencing and voice messaging,
data	text messaging, database access, graphics, EEG and ECG,
images	radiography, ultrasound, nuclear imaging, computerized tomography and nuclear magnetic resonance
video	surveillance, teaching, conferencing and television entertainment in hospital rooms.

The general trend is to digitize all these signals whenever possible and use digital storage, transmission and switching throughout. However, the majority of existing facilities (i.e. PBX and PSTN) were designed for voice and are also used for low-speed data

(up to 4.8 kb/s on a dial-up basis and 9.6 kb/s on dedicated lines). Video is still transmitted in analogue form in most cases, because digital transmission would require data rates up to 96 Mb/s or even higher for High Definition Television (HDTV) [5]. Consequently, digital transmission of video will require extensive re-design of networks. Images, on the other hand, are in greater need than video and provide an excellent opportunity to evolve the existing networks from narrowband to wideband capabilities for these reasons:

- The number of bits required for a digitized image depends on the application, thus the system could be developed first for low-resolution applications (say up to 2 Mb/image) and evolve to higher resolutions as they become economically viable.
- Transmission time for images is more flexible than for video. In a radiology department retrieval speeds should be high but in remote locations fixed delays may be acceptable. Thus, the same image can be sent at different speeds through different networks, as appropriate.

Consequently, image communications provide an excellent opportunity for network evolution.

### System description

This section discusses some of the key technical issues and service requirements of an image communications system integrated with the other communications needs in medical institutions. This is referred here as a Medical Image Communication System (MICS). Figure 1 shows a diagram of the proposed system configuration. Several papers have already appeared in the literature along these lines (e.g. [4], [6], [7], [8]). The PBX is the core of the in-building communications network and supports all the communications needs, either by itself or through peripherals. The four key sub-systems considered here are:

- 1) Image acquisition,
- 2) Image store,
- 3) Image distribution (high-speed transmission and switching) and
- 4) Visual workstations.

The general goal of this system is to optimize the cost/benefit ratio by minimizing patient and doctor displacements and materials handling (e.g. film). The system would work as follows: the image acquisition devices are located where needed, such as radiology rooms, remote radiology clinics, and even plug-in portable units. The images generated are immediately digitized at the source and sent to an image store. Visual workstations could be strategically located in radiology departments, nursing stations, surgery rooms, and doctors' offices. Doctors could access the image store from any visual workstation and examine the relevant images at any time.

Each of these sub-systems is considered now in more detail, especially the visual workstation, since this will be the interface with the users. Indeed, although all the sub-systems have strong technology requirements, the system will only be perceived through the performance at the visual workstations or terminals.

#### 1) Image acquisition

Today most imaging devices are based on film. Of course, film could be scanned and converted into a digital image but that would not be a long term solution. Indeed, it is intended that MICS will be automated as much as possible and will eliminate the use of film. Some of the imaging techniques that will generate images for the system are [1]: radiography, digital angiography, computed tomography (CT), coded apertures, endoscopy, image intensifiers, ultrasound, and nuclear magnetic resonance. The image resolutions required are different in each case. The difference between digital radiographs and other imaging techniques should be highlighted in terms of the number of bits in the digitized images. Each radiograph can generate 50 to 100 Mb (say 2000x2000 samples quantized at 12 or 13 bits) versus 1 to 4 Mb for other images (say 320x320 or 512x512 samples quantized at 12 or 13 bits). More work is required to determine the required resolutions and to develop standards. Of all the imaging techniques mentioned, radiography is the one that would produce the larger volume of bits every day. This is because of both the high resolution of radiographs and the large number of them produced in hospitals every day, as opposed to other techniques. Active research is in progress in several laboratories on digital radiography equipment which can produce a digital image directly, thus eliminating the film altogether (e.g. [9]). These products will encourage the development of MICS because without digital techniques the rest of the system does not make sense. Two types of imaging machines (or interfaces) are anticipated. First, high-volume machines such as those in radiology departments will be interfaced directly to the image store at high bit rates over dedicated lines. Secondly, there is also a need for smaller units, sometimes portable, that will be interfaced to a digital network to send the digital X-ray images to the store.

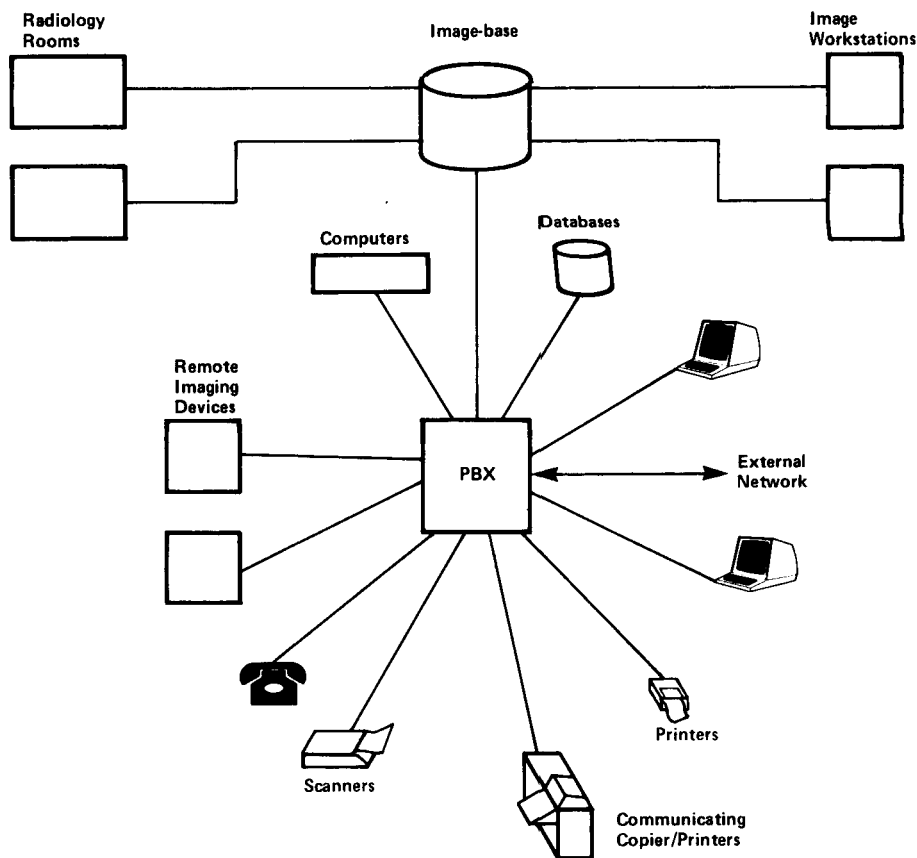


Figure 1. Medical image communication system (MICS) concept.

## 2) Image store

After the digital images have been obtained they must be kept stored for a period from 5 to 10 years (by legal standards in North America). Thus, a key component of the system is the digital mass store which will keep the large numbers of radiographs being produced in hospitals. Stores requiring capacities of one hundred thousand to one million radiographs per year are common [6]. A digital radiograph may require from 50 to 100 Mb, but with source coding [10], [11] this could be reduced to 5 or 10 Mb, which represents about 10 Tb annually [6]. Optical storage is perceived as a preferred candidate because of the projected low cost per bit. Several systems are being developed (e.g. [12]). If each optical disc can hold about 10 Gb, about 1000 discs will be needed annually. Access time would be related to the age of the radiograph [6]. Three categories are envisaged: on-line images, automated access to off-line images and manual access to off-line images. On-line access should be available for current patients in the hospital. For example, as soon as a patient enters the hospital all his records and images could be brought from archival to on-line (re-usable) storage, so that doctors can access the data without delay. Since the probability of retrieval of X-ray images is much higher during the first year, these radiographs should be accessed automatically, by using some sort of a 'juke box'. For images older than six months or one year manual mounting of optical discs would probably be more economical and the associated delays acceptable. The image store could initially use magnetic storage for applications which do not generate large numbers of bits and evolve to optical storage when these units become commercially available.

## 3) Image distribution

The images in the image-base will be accessed on-demand from the visual workstations. Suppose that the speed of transmission has to be fast enough for sending the complete image in one or two seconds. Intra-hospital workstations may require the fastest access time and remote locations will tolerate longer delays. Consequently at low resolution (say 320x320x12 bits) this implies a transmission speed of about 640 kb/s or more, while higher

resolution images (say 1000x1000x12) would require about 6 Mb/s or more (assuming that all bits in that image are transmitted). These speeds are feasible today, for example, with fibre optic transmission systems [13], [14], local area networks [15] and satellites for long distance networking. Digital switches at this high speed are not yet commercially available but they will be developed in the near future. Eventually all communication requirements will be integrated in a digital network. Future PBX designs will evolve to accommodate the needs [16], [17]. A layered design approach will ensure that older sections do not become obsolete as new capabilities are added in. In some cases an overlay network (e.g. a video switch) could be slaved to and controlled by the PBX. The PBX has two main functions: switching of internal communications and interfacing to the external network. In imaging applications circuit-switched links are preferred for the transmission of the bulk of the data (images); but packet-switching would be more efficient for the interactive part. As the network of databases and image bases grows, an intelligent network interface will be necessary to assist the users to access the desired data and also to obtain data from multiple sources.

#### 4) Visual workstation

The image workstation or visual terminal is the most important component of the system because it is the one that will be used by doctors and other medical personnel to access the image-base to examine images, as well as other medical records. Although the technology is available, the 'ideal' terminal does not exist. Indeed, even the images from those devices such as computerized tomography which are inherently digital, are still photographed today, possibly because suitable display terminals are not available yet and because of the inconvenience of loading the images from magnetic tapes, where they usually are stored. The key elements of visual workstations will be the display processor which contains the intelligence of the terminal, the display buffer or buffers to refresh the CRT, the CRT display and the controls for the human interaction. Some of the functional requirements of the visual workstation are listed here:

Image retrieval: The visual workstation will be used to access the image store, through a communications link, and will present to the viewer a reconstructed image, as selected. Any image-base could be accessed through the digital network.

Image manipulation: Since the resolution of the display may not be sufficient to present to the viewer all the information available in the image at one time; capabilities must be provided to select the intensity range, zoom, pan, roll, magnify and reduce to roam through larger images which are stored in a buffer [18]. These features must be easy to use too. The terminal will thus act as a viewing window which can easily be controlled by the user.

Image processing: The image may have not been obtained under ideal conditions (e.g. underexposed or overexposed) or it may have to be enhanced before viewing. A number of algorithms are available to accomplish this, such as [19]: intensity mappings, histogram equalization, frequency shaping (e.g. high-pass, band-pass, low pass filters), tomographic filtering [20] and pseudo-colour. It is believed that digital processing will have the most dramatic influence on each of the current image modalities [21].

Image analysis: Computer intelligence may be able to assist the doctor in diagnosing the image by using pattern recognition processes, area or volume measurements, etc. In certain specialized cases the doctor could be assisted by the machine which would present to him the appropriate sequences of image sub-sections automatically, although it would be the doctor who would diagnose and be in control at all times.

Image comparison: Many medical examinations involve comparing a number of images: current image vs. a 'normal' one (from a reference file), current image vs. a previous one, images with and without a dye previously injected (subtraction), etc. Instead of having multi-screen terminals a single-screen multi-buffer configuration can be used to flip quickly from image to image. Other possibilities are split-screen displays and superposition with user-controlled continuous fading from one image to the next.

Image conferencing: It is often required that two or more doctors discuss the same image for consultation, training, or prior to surgical procedures. A medical image communications system could facilitate image conferencing by providing a common visual space on a number of separated workstations. The doctors could talk freely while looking at the image, as well as making annotations, pointing to trouble spots, etc. Any image manipulation/processing done by one of the doctors would be seen immediately by the others because only change commands would be communicated during the electronic meeting, not the images themselves. It would also be possible to go to previous stages of discussion because the changes would be organized in overlaying planes. For further details of these techniques refer to the interactive visual communications developments in BNR [22], [23].

To summarize and put into perspective the previous features consider the following mode of operation: A doctor or his assistant can check the status of the ordered medical tests and imaging on their terminals (or else they could be alerted automatically by the system when the results become available). The doctor is presented with the latest image(s). During the examination he can manipulate the image, process it, select previous radiographs or standard images from catalogues, consult with specialists if necessary, and accomplish all this without any delays because of the integration of all functions in an easy-to-use visual terminal connected to a digital network. To prepare the report it could be dictated as is customary in hospitals, but instead of being typed, a voice store-and-forward feature associated with the PBX could send the report to the word processing department. Ultimately, automatic voice recognition systems could code the dictated report [24]. The doctor (or his assistant) could then review the report seconds later. A reduced version of the radiograph could be presented on the screen together with the written report, and the doctor could sign it. Annotations to the image itself would also be possible. This report would then be distributed electronically and on-demand to the doctors wishing to see it.

Since the human factors design of the workstation is crucial a few comments are in order. The most important performance characteristic of the visual workstation is speed. Indeed, doctors will be able to diagnose many more cases than they do now if the cumbersome and time consuming tasks of film handling, comparison and viewing are replaced by very fast electronic filing, retrieval, processing and display. The second requirement is a well engineered human interface so that the viewing operations do not require extensive training and are an extension of normal habits. Studies of this nature have been conducted for interactive computer terminals (e.g. [25], [26], [27], [28]); but for imaging, further studies of interactive needs will be necessary.

To provide easy access, workstations should be conveniently located and there should be an adequate supply of them. If each needs a display processor, they will surely be expensive. One solution is to develop a family of terminals with various degrees of sophistication, so that each user has the capabilities relevant to him. At one end of the scale there would be simple desk top terminals such as Displayphone [29]. At the other end of the scale there would be sophisticated workstations for use by specialists in radiology departments. Another approach (compatible also with the family of terminals) is to centralize the expensive components so that they can be shared. In the following section this alternative is examined in more detail.

#### Terminal communications alternatives

As established, a significant cost component of the system is that of the visual workstations. It was suggested that a family of terminals with different capabilities would allocate resources more cost-effectively. Other configurations could achieve a higher utilization of resources by centralizing those components which could be shared and accessing the resources through communications and switching. These will now be discussed and compared.

Consider the current configuration of image processing systems [30]: a sophisticated display terminal is connected to a host system. Although the host could perform processing operations on the image, most functions are implemented in the terminal to gain speed. For the purposes of this analysis only four functional blocks are considered in the overall system:

- the host or database (includes the image store, unusual processing capabilities, link to other databases, batch processing, etc.)
- the display processor (DP) with one or more frame buffers (where the intelligence of the terminal is located)
- the digital to analogue converters (DAC) (which also format the digital signal to video format, as appropriate)
- the display

Figure 2 shows these four components while Figure 3 shows four ways in which multi-station systems could be configured. The dashed lines in Figure 2 indicate for each case where communications and switching could be introduced. The components to the right of the dashed line would be in each terminal and those to the left would be shared.

The problem of optimizing the division of functions between functional blocks has been studied for graphics terminals [31]. Too much freedom could result in unwieldy designs; consequently, relative performance and cost for only four basic configurations will be compared here. Each takes advantage of resource sharing and switching by centralizing the expensive components to various degrees. This means that not all terminals can perform all functions at the same time, but it is normal for some terminals to be idle at times.

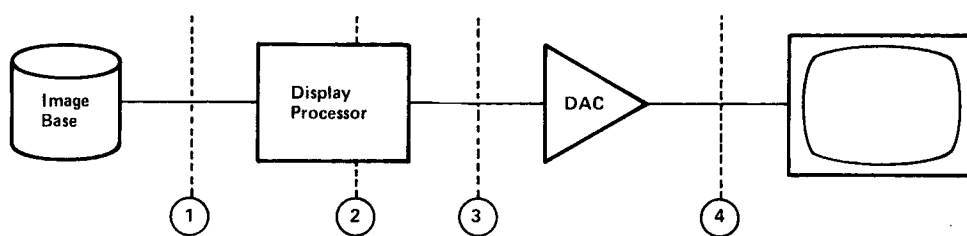
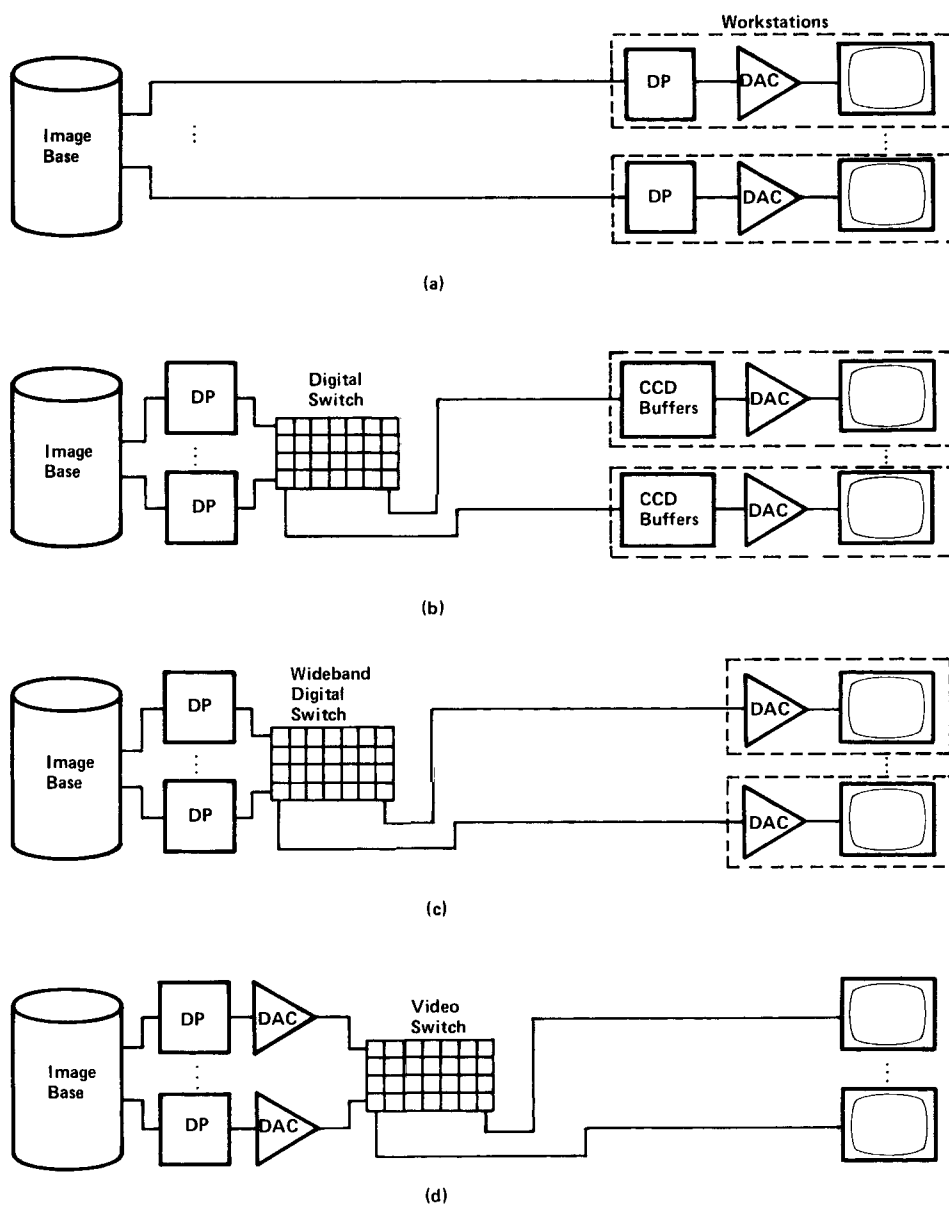


Figure 2. Possibilities for terminal configurations.



DP = Display Processor  
DAC = Digital to Analog Converter

Figure 3. Multiple workstation configurations.

Configuration 1 (Figure 3(a)) is the normal mode of operation of image processing systems. Sophisticated systems are connected to a host/image-base computer over a dedicated link. Since each workstation contains a display processor, buffers etc., this is the most expensive configuration. It also provides the greatest independence from the centralized facilities. The data rate required between the image base and the terminal would be about 6 Mb/s for 2 seconds transmission of a 12 Mb image (640 kb/s for a 2 Mb image).

Configuration 2 (Figure 3(b)) divides the display processor in two parts. The centralized part is shared. Thus, not all terminals can make use of the centralized facilities at the same time, because there is a degree of concentration. A simple way to partition the display processor would be, for example, to keep a RAM buffer and all the processing power in the centralized facilities and to configure the terminal with several CCD refresh memories [32]. These multiple buffers provide facilities that would enable the necessary speed to flip from one image to another. The cost would be lower than that of Configuration 1 because of the sharing of resources. A digital switch or concentrator would be required between the host database and the terminal. Speeds required would be as in Configuration 1 (say 640 kb/s to 6 Mb/s) or faster.

Configuration 3 (Figure 3(c)) does not keep any buffer at the terminal, meaning that the CRT is refreshed digitally from the central facilities. This would apparently be even cheaper than Configuration 2 because of the higher degree of sharing; however the data rates required to refresh the terminal digitally would be very high (up to 240 Mb/s).

Configuration 4 (Figure 3(d)) maximizes the degree of centralization by including the analogue to digital converters. This means that transmission is analogue video through video links and video switches. This is possibly the most inexpensive solution; however the quality may not be sufficient depending on the losses in the video switch and transmission, as well as immunity to noise. Furthermore, NTSC-standard television (525 lines) may not be sufficient in some applications and HDTV [5] may be required.

### System Evolution

Costs can also be minimized by taking advantage of existing communication facilities. For example, the capability of existing in-building twisted pairs for telephone/data applications in hospitals could be pushed to carry data at speeds higher than usual over short distances (say 64 kb/s). For example, a 320x320x12 image could be transmitted at 64 kb/s in 19 seconds or at 640 kb/s in 1.9 seconds. Source coding can reduce storage and transmission time further. The use of existing network facilities could also be an interim solution for remote terminals which are not heavily used and may tolerate a lower grade of service. On the other hand, new installations as well as evolving ones would make use of state of the art technology, such as fibre optics, to get the highest speeds. System evolution can also be accomplished by implementing first those imaging services that require the lowest data rates and could make use of standard television technology. This suggests that in terms of storage requirements, speed and terminal equipment, the systems could naturally evolve from the lower resolution applications to the higher resolution ones as new technology is applied. PBX design will continue to evolve to satisfy the needs as the requirements for higher data rates are established. The digital telephone network also favours evolution because it is organized in channel multiples of 64 kb/s (56 kb/s usable for data). This permits an evolutionary path to be mapped starting from low data rates (say 9.6 kb/s) to 64 kb/s and multiples of 64 kb/s channels (nx64 kb/s) that would eventually lead to a truly broadband network for the new services. 'Long-distance' networking of medical image communication systems could be done by means of satellites or future terrestrial wideband digital networks.

### Conclusions

In this paper a medical image communication system has been described. The key sub-systems, technology issues and service/system requirements have been discussed. Solutions have been proposed for the design of cost-effective systems. Research and development will be required in all the areas outlined to ensure successful introduction of Medical Image Communications Systems (MICS). In particular, resolution standards for medical imaging, human interface requirements for visual workstations and image-base management systems will require careful study. Since the problems are multi-disciplinary, solutions will only be possible by active participation of the experts in the various disciplines, such as medicine, imaging technologies, communication and computer systems and terminal design.

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