

Image and Medical Data Communication Protocols for Telemedicine and Teleradiology

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**Image and Medical Data
Communication Protocols for
Telemedicine and Teleradiology**



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*to my
dad and mom.*

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Abstract

Telemedicine is currently being used to bridge the physical distance between patients in remote areas and medical specialists around the world. Distributed client-server applications have become very popular with the explosive growth of the Internet. These distributed applications provide an inexpensive and fast way to access medical information and also provide good accessibility and availability of medical service. Telemedicine applications are a client/server applications where medical and patient information is stored in a server and the information is made accessible to doctors and medical personnel at a distant site. In addition, depending on the type and the needs of the medical application different type of communication protocols and medical devices are utilized making interoperability and communication over different communication channels quite difficult. In my dissertation I analyzed first a range of telemedicine systems already used and I concluded that telemedicine systems can be categorized according to on three different features (layers):

- Transportation protocol layer
- Medical devices layer
- Application layer

The outcome of the analysis was that on the application layer, there exists a wide variety of different telemedical applications, each one supporting a special and focused medical application case. Thus, on the application layer a heterogeneous environment of medical use cases exists and it not possible to homogenize due to the particularities of each medical situation.

Regarding the device layer, a plurality of different medical devices is used for each medical application supporting different functionality. As an example, one uses ECG devices for monitoring heard activity, blood pressure devices to measure the diastolic and systolic arterial pressure, ultrasound, CT, MRI devices for medical imaging analyzing physiological structures and so on. Nevertheless, although the individual devices will have to remain separate, I propose here an interfacing scheme enabling connection of the various devices to a unique data interface, enabling their individual data to be transferred and handled in a unique, transparent way. By this I integrated a wide variety of medical devices offering

flexible solutions covering large number of home care, emergency and radiology applications.

On the transportation layer I concluded that a number of various telecommunication protocols are utilized and miscellaneous types of data types and data sizes are to be exchanged, depending on their application. In addition, I concluded that all the communication protocols applied today show common problems emerging from firewalls and network address translation servers. I also concluded that the applied communication protocols do not support presence awareness of the users.

Based on the aforementioned observations, I propose an instant messaging protocol able to homogenize the communication and transportation layer and support any data type and any data size while solving all of the existing problems at once. In this way I unified the various protocols, replacing them by only one, at the same time overcoming common problems arising from firewalls, NATs and mobility of the users.

Traumastation shows exemplarily the correctness of my approach and demonstrates how several different medical devices can be integrated on one single case and support a wide variety of applications utilising thereby one single data transportation protocol.

Chapter 1

Introduction

1.1 Motivation

Telemedicine is as old as Greek mythology. In Homer's Iliad we could find the first application in the Trojan War. Information concerning Achilles' injury was transmitted with the help of *fryctories* - fire smoke - from Troy to mainland Greece.

For more than 30 years clinicians, health services researchers, and others have been investigating the use of advanced telecommunications and information technologies to improve health care. At the intersection of many of these efforts lies telemedicine, a combination of innovative and mainstream technologies. As defined, **telemedicine is the use of electronic information and communications technologies to provide and support health care when distance separates the participants**[1].

In more recent years, telemedicine has had a variety of applications in patient care, education, research, administration, and public health [2]. Some uses such as emergency calls using ordinary telephones are so commonplace that they are often overlooked as examples of distance medicine [3, 4]. Other applications such as telesurgery involve exotic technologies and procedures that are still in the experimental stage. The use of interactive video [5] for such varied purposes as psychiatric consultations and home monitoring of patients [6] attracts much attention and news coverage, although such applications are far from in everyday medical practice.

Early applications often focused on remote populations scattered across mountainous areas, islands, open plains, and arctic regions where medical specialists and some times primary care practitioners were not easily reached [7]. Most of the telemedicine projects from the 1960s through the early 1980s failed, however, to survive the end of grant-funding or trial-financing. Telecommunications costs tended to be high, and the technologies were awkward to use.

Recently, another wave of interest in telemedicine has prompted a range of new activities. Costs have dropped for many of the information and communications technologies supporting telemedicine [8, 9]. Teleradiology appears to be the most common application [10], in part because insurance agents and other payers reimburse for radiology consultations without demanding the face-to-face relationship required for most other consultations

[11, 12, 13].

With the nation's health care system undergoing profound changes and experiencing relentless financial pressures, telemedicine is being investigated for its utility in urban as well as rural settings. To the extent that telemedicine offers a mechanism for centralizing specialists and supporting primary care clinicians, managed care plans may find certain applications efficient and attractive in the cities and suburbs where their patients are concentrated.

Some academic medical centers and other organizations, faced with reduced revenues and even exclusion from local managed care networks, are exploring telemedicine as they seek to develop new regional, national, and international markets for their highly specialized clinicians. In these contexts, telemedicine has the potential to radically reshape health care in both positive and negative ways and to fundamentally alter the personal face-to-face relationship that has been the model for medical care for generations.

1.2 Current Problems

In developed countries telemedicine applications would be treated as a luxury; primarily as research or education tools. On the other side, in poor and developing countries, in Africa and Latin America [14, 15], telemedicine would play a vital role to health administration and treatment.

The lack of specialist doctors in rural and isolated areas causes many patients to be transferred to urban hospitals for diagnosis and treatment.

In the existing primary care, physicians often need to consult a specialist at a referral hospital for security as well. Additionally, patients with chronic illness, as well as those who are in post post-surgery state or predisposed to heavy illness, need a form of monitoring of their health until their condition becomes stable or deemed not hazardous (Home monitoring). The patients as well as their family and friends also need an efficient way to collaborate with their doctor and get informed about their condition. Until today, monitoring of the health condition of such people could only be performed by prearranged visits from a doctor or by visits to the local hospital for a checkup. This is, however, an inefficient solution, as well as costly, as these visits would scarcely be on day by day basis.

Furthermore, the population is getting older [16], increasing the demand for long-term care, often at home, with fewer facilities and medical staff available per patient. Consequently, fewer doctors per patient are available, which results in deterioration of the quality of services provided by the health systems. Nowadays, the current ratio of physicians to doctors is 270 physicians per 100.000 citizens. However, the population is rapidly aging, and the larger segment is 85 plus category. Unfortunately, that age group needs more than 780 physicians per 100.000 [17]. This situation represents an important challenge for our society and it is urgent to provide consistent solutions to avoid deep deterioration of the quality of our society, citizens all over the world and particularly in development countries (Aged people Assisted Living-AAL).

Providing the correct medical application, the doctors are able to monitor the patient more frequently, without leaving their offices. Furthermore, any person, for instance family or

friends, can check the patient's health condition anytime from virtually everywhere [18, 19].

Distributed client/server applications have become very popular with the explosive growth of the Internet [2, 20, 21, 22]. These distributed applications provide us with an inexpensive way to access information and also provide good accessibility and availability of information. Telemedicine applications are client/server applications where medical and patient information is stored in a server, and the information is made accessible to doctors and medical personnel at a distant site.

In telemedicine there are varieties of applications in each medical area. Each application uses a specific type of medical device. For instance, in radiology an ultrasound device can be utilized. In home-care medicine, an ECG and blood pressure device can be placed. In addition, each application makes use of different protocols for real-time and store-and-forward communication. Different protocols are applied in each case and also they face common problems when the users are located behind firewalls and network address translation servers (NATs). Users behind NATs are able to initiate and establish any connection from their internal network to the Internet (external network). However, users located at the external network (Internet) are not able to initiate and establish communication with users behind a NAT.

In addition, physicians are working in a very complex environment and they need to have access to medical data from any place and any time. Furthermore, we have to take into account the constantly growing number of medical images and we need to explore new methods for data handling. As shown in Figure 1.1 the number of CT studies increased almost 5.5 times within the last seven (7) years. The number of the images per study is also increased, from an average of 69 in 1998 to 234 images per study in 2006 [23]. Figure 1.2 shows the 8-year growth in storage demand resulting from these two trends. For CT storage as well as the radiology data in general, the trend will continue to increase [25]. In addition, we have to take into account that CT manufactures will eventually move to 1024x1024 matrix size CT data sets. The complexity and range of telecommunication technology requirements vary with specific medical applications. In a telemedicine application digital medical devices impose the telecommunication performance requirements.

1.3 Topic and structure

The target of my dissertation is to provide a homogeneous telemedicine system able to support the widest possible variety of applications, offering a maximum on homogeneous environment.

In the second chapter of my dissertation I present the state-of-the-art and introduce a taxonomy of telemedicine systems providing a categorization of all available telemedical applications. Summarizing, telemedicine systems can be categorized according to on three different features (layers):

- Transportation protocol layer
- Medical devices layer
- Application layer

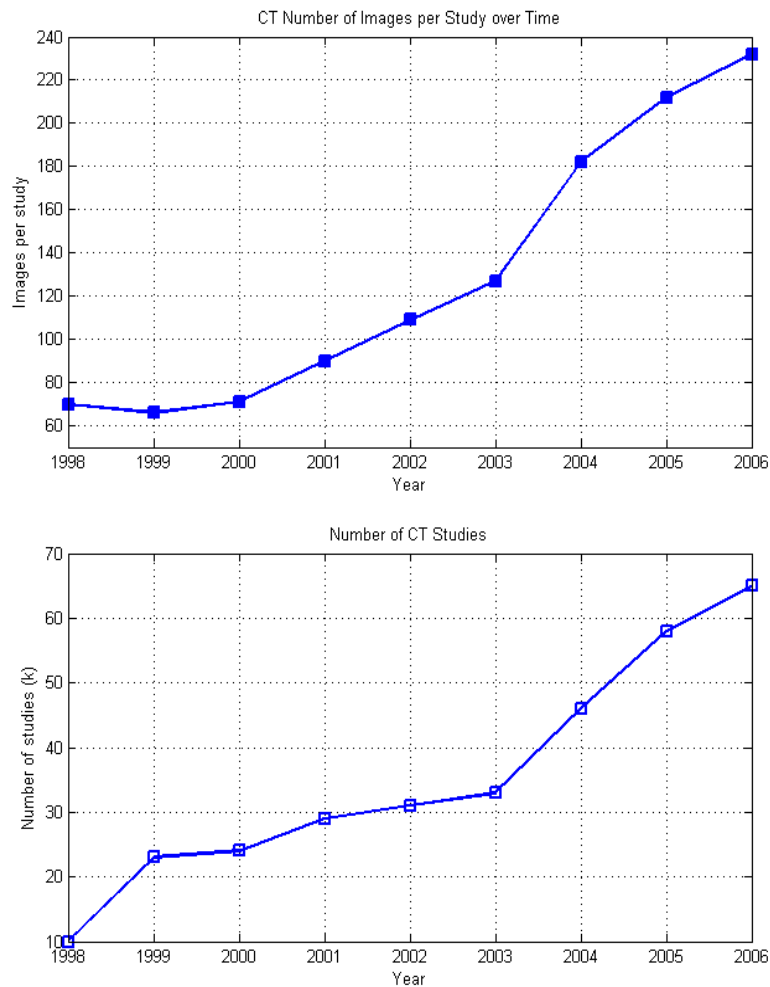


Figure 1.1: Growth in number of images per study and number of CT studies performed between 1998 and 2006

Based on this taxonomy I am positioning this dissertation and I depict the needs of integrating and unifying different layers of the telemedical systems. In the third chapter I provide a solution that uses just one protocol for imaging and medical data exchange. I propose a unified protocol that covers all aspects of telemedical applications and also bypasses problematic areas.

In the fourth chapter I am proposing the integration of medical devices. Traumastation is such an integrated device that shows exemplarily the correctness of my approach of how several different devices can be integrated on one single case and support a wide variety of applications, thereby utilising one single protocol. In addition, a medication monitoring device and system is introduced for monitoring patients' medication adherence in home environment.

In the fifth chapter I depict various telemedicine applications where my developments were applied. Due to the nature of the medical environment and needs, the application layer will always remain inhomogeneous and focused on different applications. However the

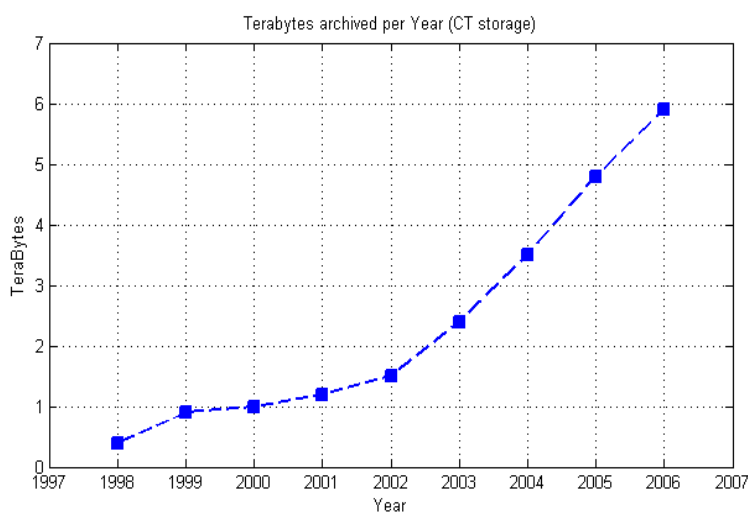


Figure 1.2: CT storage used per year

presented applications prove the correctness of my approach and its ability to support a wide variety of applications within a single and homogeneous environment.

I conclude with chapter six where I summarized my developments and achievements and also providing a view of future telemedicine system and trends.

1.4 Main results

Following the taxonomy of the telemedicine systems, I was able to provide a unification of all transportation protocols making use of an instant messaging protocol for exchanging all types of data (medical imaging, vital parameters, collaboration and application sharing etc.). In addition, I integrated a variety of medical devices into a portable medical case (TraumaStation) that can be used and support a range of medical applications utilizing just one transportation protocol.

In more details, I extended the communication component and the communication functionality of my imaging collaboration platform. I developed a general framework of communication based on instant messaging protocol and unified the different types of appropriate protocols and techniques used for exchanging data. The information exchange is independent of the communication channel used (satellite, Internet, UMTS, WLAN, etc.) and overcomes barriers occurred by firewalls and NAT (Network Address Translation) servers.

Through out my developments and extensions I supported the mobility of the medical imaging collaboration platform, making use of instant messaging (IM) protocol. I also provided my extensions to the instant messaging protocol to support transportation of binary data and large volumes of data, Furthermore, I introduced two methods, synchronous and asynchronous, for collaboration among physicians over IM.

In addition, I designed and built a portable telemedicine kit (so-called Traumastation) as illustrated in Figure 1.3. This portable telemedicine unit has been tested in the field and is able to address the remote diagnostic needs of patients in rural communities as well as for



Figure 1.3: Traumastation

emergency and in home environment. Traumastation integrated numerous medical devices in one box and has been validated over several years and in various projects in countries in urban and rural locations of Latin America.

Concluding, I also developed a medical home care application for monitoring patients' vital signals and medication adherence in distant locations both in real time and in a store-and-forward mode. Particularly, I developed an algorithm for detecting the medication adherence of patients. The algorithm is based on image processing for predicting patients' behavior.

Chapter 2

State-of-the-art

2.1 Telemedicine taxonomy

Telemedicine is the use of electronic information and communication technologies to provide and support health care when distance separates the participants [10]. It is a system that connects primary care physicians, providers, specialists and patients. Telemedicine is not a new concept. It has existed for a number of years in the form of the telephone and fax machines. In recent years, with the improvements made in access, technology, and communications systems, telemedicine has expanded and, in a time of limited resources, has become a feasible alternative for smaller and rural medical facilities to provide routine and specialized services. Particularly in rural areas, it offers the potential of both improved access to care and improved quality of care.

The primary applications of telemedicine are clinical, educational, administrative, and research [24].

- Clinical applications include initial patient evaluations, diagnosis (telediagnosis), and consultation (teleconsultation). Physician supervision of non-physicians and monitoring of patient status are possible.
- Continuing education for professionals is available, as is patient and community education (tele-education).
- Administrative uses, such as conferences, scheduling, and utilization and quality review may be provided.
- Research is enhanced by aggregation of data from multiple sources and coordination.

Telemedicine allows access to the wealth of information available on the Internet [25, 26, 27, 28, 29, 30, 31, 20]. This allows information to be obtained at the touch of a finger. The availability of e-mail allows an efficient mechanism of communication between consulting and primary physicians [32, 33, 34, 35, 36].

The telecommunication infrastructure provides the technology to move information in an electronic way between geographical locations. Participating sites are connected via electronic networks. The telecommunication medium utilized by telemedicine programs is

determined in large part by the available local infrastructure. The communication could include satellite, microwaves link or terrestrial lines (either twisted copper phone lines or fiber optic lines).

For the telemedicine system I have defined a taxonomy architecture that categorizes the telemedicine systems in terms of communication protocols, telemedicine devices, and telemedicine application in clinical domain, as shown in table 2.1.

	Home care	Emergency	Radiology
Applications	TOPCARE, TeLeCare	DELTASS, REMSAT	Chili, DicomWorks
Devices	Medication dispenser, ECG, glucose, BP, SPO2	ECG, SPO2, BP	Ultrasound, MRI, CT, PET
Protocols	Appropriate P2P, HTTPS	Appropriate P2P	Appropriate P2P, DICOM, HTTPS, email

Table 2.1: Taxonomy of telemedicine systems

Telemedicine can be divided into home-care, emergency and radiology telemedicine where user defined applications can be utilized. Each type of telemedicine makes use of dedicated medical devices for medical data acquisition. In addition, the transmission of the recorded data and data communication is utilized over various types of communication networks and various communication protocols.

The applications are based on the variety of networks, ranging from the ordinary telephone lines to specialized networks. Telemedicine involves a spectrum of technologies including computer technology, digital imaging, video conferencing, remote monitor, file sharing, networking and telecommunications. Nowadays, we meet telemedicine applications in home care environments, in emergency and radiology domains.

2.2 Telemedicine protocols

In this section I will focus on *telemedicine protocols* used by all types of telemedicine applications in home care, emergency and radiology domains. Telemedical applications have the need to transmit and receive text, images, and sounds. Text includes ECG results (heart tracings), laboratory results and patient records. Images range from still photographs to full motion imagery. Radiological images, slides and graphics may be transmitted, as well as voice and chest sounds.

Transmission may be done in one of two methods [37]:

1. **Real-time** transmission is utilized when immediate feedback is essential. Emergency triage, interactive treating situations [38] [39] and meetings are a few examples.
2. **Store-and-forward** When immediate feedback is not required, store-and-forward may be implemented. Data is stored, forwarded and accessed at the hub at a sched-

	Home care	Emergency	Radiology
Applications	TOPCARE, TeLeCare	DELTASS, REMSAT	Chili, DicomWorks
Devices	Medication dispenser, ECG, glucose, BP, SPO2	ECG, SPO2, BP	Ultrasound, MRI, CT, PET
Protocols	<i>Appropriate P2P, HTTPS</i>	<i>Appropriate P2P</i>	<i>Appropriate P2P, DICOM, HTTPS, e-mail</i>

Table 2.2: Taxonomy of telemedicine systems

uled time or at the convenience of the hub personnel. This is less costly as data can be compressed and batched for transmission [40] [41].

The transmission mode may be transported via satellite [42, 43, 44] or terrestrial [45] media. Terrestrial modes include microwave, fiber-optic, and conditioned copper cables. Satellite transmission allows a full motion broadcast quality picture.

Satellite transmissions have no boundary restrictions. It allows transmission of large amounts of information. It is ideal for sending visual information to multiple locations. The disadvantage is the cost, but it is the only way to provide communication means to isolated areas [46, 47, 48, 49, 50].

Terrestrial transmission is less expensive to operate on an hourly basis but is limited to areas that are linked to the appropriate line [51, 52, 53, 54].

Nowadays, the dominant means of communication is the internet and basically all medical applications make use or have a gateway over TCP/IP [55].

Most applications in home-care use appropriate P2P (point-to-point) developments for data transmission or https protocols. However, most of the applications work in store-and-forward mode.

Emergency applications need real-time transmission and use appropriate P2P developed protocols for data exchange that add huge configuration efforts during system installation. In addition, dedicated ports need to be opened for bi-directional communication.

In radiology domains both real-time and store-and-forward communication can be applied, although most dominant is the store-and-forward mode, making use of e-mail protocol (SMTP, IMAP and POP3). Furthermore, DICOM protocol is used in hospital settings providing intercommunication among different medical departments. When an external access to the medical data is needed, normally the HTTPS protocol is utilized.

2.3 Telemedicine devices

In this section I will focus on *devices* used by all types of telemedicine applications in home care, emergency and radiology domain. Medical peripheral devices are used to capture images, anatomic sounds or other physiologic images. Medical peripherals can be categorized into two general groups based on what type of information they capture. We have the

	Home care	Emergency	Radiology
Applications	TOPCARE, TeLeCare	DELTASS, REMSAT	Chili, DicomWorks
Devices	<i>Medication dispenser, ECG, glucose, BP, SPO2</i>	<i>ECG, SPO2, BP</i>	<i>Ultrasound, MRI, CT, PET</i>
Protocols	Appropriate P2P, HTTPS	Appropriate P2P	Appropriate P2P, DICOM, HTTPS, e-mail

Table 2.3: Taxonomy of telemedicine systems



Figure 2.1: An ultrasound device device

imaging devices such as ultrasound, CT, MRI and PET cameras that capture images. The second general group of medical peripherals captures vital signals such as ECG, blood pressure, oxygen saturation and temperature. In the second group we could add one more device that is used for monitoring patient's medication adherence. This is the medication dispenser.

Ultrasound

Ultrasound imaging is a common diagnostic medical procedure that uses high-frequency sound waves to produce dynamic images (sonograms) of organs, tissues, or blood flow inside the body. Prenatal ultrasound examinations are performed by trained professionals, such as sonographers, radiologists, and obstetricians. The procedure involves using a transducer, which sends a stream of high-frequency sound waves into the body and detects their echoes as they bounce off internal structures. The sound waves are then converted to electric impulses, which are processed to form an image displayed on a computer monitor. It is from these images that videos and portraits are made.

CT

Computed tomography (CT) imaging, also referred to as a computed axial tomography (CAT) scan, involves the use of rotating x-ray equipment, combined with a digital computer, to obtain images of the body. Using CT imaging, cross sectional images of body organs and tissues can be produced. Though there are many other imaging techniques, CT imaging has the unique ability to offer clear images of different types of tissue. CT imaging can provide views of soft tissue, bone, muscle, and blood vessels, without sacrificing clarity. Other imaging techniques are much more limited in the types of images they can provide.

CT imaging is commonly used for diagnostic purposes. In fact, it is a chief imaging method used in diagnosing a variety of cancers, including those affecting the lungs, pancreas, and liver. Using CT imaging, not only can physicians confirm that tumors exist, but they can also pinpoint their locations, accurately measure the size of tumors, and determine whether or not they have spread to neighboring tissues.

In addition to the diagnosis of certain cancers, CT imaging is used for planning and administering radiation cancer treatments, as well as for planning certain types of surgeries. It is useful for guiding biopsies and a range of other procedures categorized as minimally invasive. Thanks to its ability to provide clear images of bone, muscle, and blood vessels, CT imaging is a valuable tool for the diagnosis and treatment of musculoskeletal disorders and injuries. It is often used to measure bone mineral density and to detect injuries to internal organs. CT imaging is even used for the diagnosis and treatment of certain vascular diseases that, undetected and untreated, have the potential to cause renal failure, stroke, or death.

MRI

MRI Stands for Magnetic Resonance Imaging; once called Nuclear Magnetic Resonance Imaging. The Nuclear was dropped off about 15 years ago because of fears that people would think there was something radioactive involved, which there is not.

MRI is a way of getting pictures of various parts of your body without the use of x-rays, unlike regular x-rays pictures and CAT scans. A MRI scanner consists of a large and very strong magnet in which the patient lies. A radio wave antenna is used to send signals* to the body and then receive signals back. These returning signals are converted into pictures by a computer attached to the scanner. Pictures of almost any part of your body can be obtained at almost any particular angle

PET

Depending on the type of nuclear medicine exam you are undergoing, the radiotracer is either injected into a vein, swallowed or inhaled as a gas and eventually accumulates in the organ or area of your body being examined, where it gives off energy in the form of gamma rays. This energy is detected by a device called a gamma camera, a (positron emission tomography) PET scanner and/or probe. These devices work together with a computer to measure the amount of radiotracer absorbed by your body and to produce special pictures offering details on both the structure and function of organs and tissues.



Figure 2.2: Ambulatory blood pressure device

A PET scan measures important body functions, such as blood flow, oxygen use, and sugar (glucose) metabolism, to help doctors evaluate how well organs and tissues are functioning

Blood pressure

The blood pressure meter measures the arterial blood pressure. Blood pressure is the pressure exerted by the blood perpendicular to the walls of the blood vessels. Unless indicated otherwise, blood pressure refers to systemic arterial blood pressure, i.e., the pressure in the large arteries delivering blood to body parts other than the lungs, such as the brachial artery (in the arm). Figure 2.2 shows an ambulatory blood pressure device [56].

Oscillometric methods are used in the long-term measurement and sometimes in general practice. The equipment is functionally the same as for the auscultatory method, but with an electronic pressure sensor (transducer) fitted in the cuff to detect blood flow, instead of using the stethoscope and the expert's ear. In practice, the manometer is a calibrated electronic device with a numerical readout of blood pressure. To maintain accuracy, calibration must be checked periodically, unlike for the inherently accurate mercury manometer. In most cases the cuff is inflated and released by an electrically operated pump and valve, and it may be fitted on the wrist (elevated to heart height), although the upper arm is preferred. They often vary widely in accuracy, and should be checked at specified intervals and if necessary recalibrated. Oscillometric measurement requires less skill than the auscultatory technique, and may be suitable for use by non-trained staff and for automated patient monitoring. The cuff is inflated to a pressure initially in excess of the systolic blood pressure, reducing to below diastolic pressure over a period of about 30 seconds. When blood flow is nil (cuff pressure exceeding systolic pressure) or unimpeded (cuff pressure



Figure 2.3: Blood oxygen saturation device

below diastolic pressure), cuff pressure will be essentially constant. When blood flow is present, but restricted, the cuff pressure, which is monitored by the pressure sensor, will vary periodically in synchrony with the cyclic expansion and contraction of the brachial artery, i.e., it will oscillate. The values of systolic and diastolic pressure are computed from the raw measurements by use of an appropriate algorithm, and displayed.

In practice the different methods do not give identical results; an algorithm and experimentally obtained coefficients are used to adjust the oscillometric results to give readings which match the auscultatory as well as possible. Some equipment uses computer-aided analysis of the instantaneous blood pressure waveform to determine the systolic, mean, and diastolic points. The term NIBP, for non-invasive blood pressure, is often used to describe oscillometric monitoring equipment [57].

Oximeter

The Oximeter determines SpO₂ and pulse rate by passing two wavelengths of low intensity light, one red and one infrared, through body tissue to a photodetector.

During measurement, the signal strength resulting from each light-source depends on the color and thickness of the body tissue, the sensor placement, the intensity of the light sources, and the absorption of the arterial and venous blood (including the time varying effects of the pulse) in the body tissues. The Oximeter processes these signals, separating the time invariant parameters (tissue thickness, skin color, light intensity, and venous blood) from the time variant parameters (arterial volume and SpO₂) to identify the pulse rate and calculate oxygen saturation. Oxygen saturation calculations can be performed because oxygen saturated blood predictably absorbs less red light than oxygen depleted blood.

Since measurement of SpO₂ depends on a pulsating vascular bed, any condition that restricts blood flow, such as use of a blood pressure cuff or extremes in systemic vascular resistance may cause an inability to determine an accurate pulse and SpO₂ readings.



Figure 2.4: ECG Device (CardioPerfect PC based ECG)

ECG

According to medicinenet.com, the electrocardiogram (ECG or EKG) is a noninvasive test that is used to reflect underlying heart condition by measuring the electrical activity of the heart. Leads (electrical sensing devices) must to be positioned on the body in standardized places. Studying the characteristic of the electrical signal generated, heart conditions can be drawn. The electrical activity generated by the heart can be measured by an array of electrodes located on the body. An ECG device is shown in Figure 2.4. Outcomes of the ECG device can be stored on PCs and get analysed in real-time.

Medication dispenser

A medication dispenser, or pill dispenser, is a device which alerts and monitors intake of medication. Adherence to (or compliance with) a medication regimen is generally defined as the extent to which patients take medications as prescribed by their health care providers. The word *adherence* is preferred by many health care providers, because *compliance* suggests that the patient is passively following the doctor's orders and that the treatment plan is not based on a therapeutic alliance or contract established between the patient and the physician.

In the following chapter 4.2, I am going to describe a new method for the prediction of the medication adherence, based on medical imaging analysis.

2.4 Telemedicine applications

In this section I will focus on the variety of *telemedicine applications* in home-care, emergency and radiology domain.

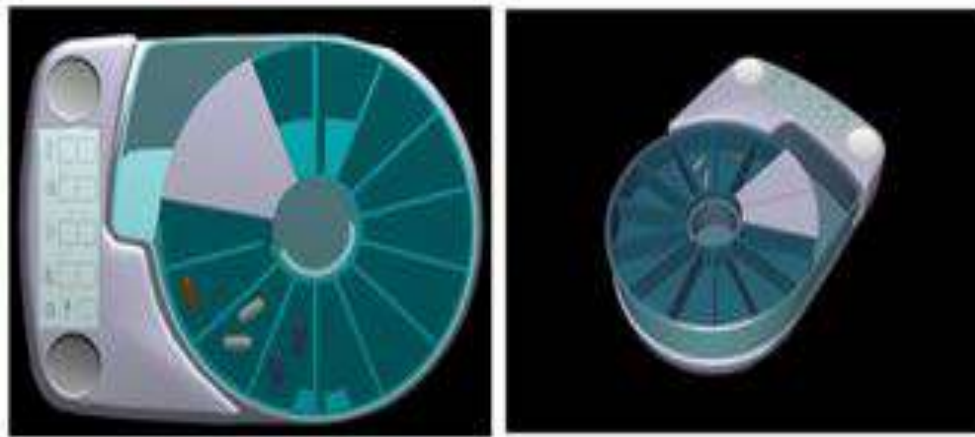


Figure 2.5: Medication dispenser

	Home care	Emergency	Radiology
<i>Applications</i>	<i>TOPCARE, TeLeCare</i>	<i>DELTAASS, REMSAT</i>	<i>Chili, Dicom-Works</i>
<i>Devices</i>	Medication dispenser, ECG, glucose, BP, SPO2	ECG, SPO2, BP	Ultrasound, MRI, CT, PET
Protocols	Appropriate P2P, HTTPS	Appropriate P2P	Appropriate P2P, DICOM, HTTPS, e-mail

Table 2.4: Taxonomy of telemedicine systems

DELTAASS

DELTAASS (Disaster Emergency Logistic Telemedicine Advanced Satellite System) is a space based system designed to improve the benefits and efficiency of the management of the rescue, first medical aid and emergency operations in disaster situations like earthquakes or explosions. In such situations, the existing terrestrial infrastructures could be damaged. The space systems then suitably complement partly destroyed terrestrial infrastructures to answer to the requirements of emergency healthcare services such as fast deployment of the management of the logistic and medical means or remote medical expertise.

The DELTAASS system enables the mobile paramedical or medical teams to co-ordinate their medical actions towards victims, to generate and transmit localisation and medical data directly from the disaster fields to a coordination centre in an automatic and easy way, using adapted light space-backed equipment. The DELTAASS system also allows distant medical equipment or images manipulations and real time telediagnosis by specialised medical doctors on remote sites.

DELTAASS is based on the requirements of healthcare services in disaster situations. Its concept also covers other operational mobile applications needs.

The different components of the DELTAASS system are:

- Mobile Teams (MT) - deployed on the disaster site for search, first triage and victim



Figure 2.6: DELTASS overview

evacuation. They are equipped with portable telephone and PDA's and/or Portable Telemedicine Workstation (PTW) for transmission of locally recorded data to the Permanent Centre (PC) or to the Mobile Field Hospital (MFH) operators. MT's are equipped with GPS for real time localisation and data transfer to PC's and MFH's. Equipment allows phone communication between them and the PC or MFH and other hospitals.

- A Permanent Centre (PC). Possibly located in a region providing humanitarian help. It receives voice and data communications from MT's, manages and redirects this to a Reference Hospital (RH) and MFH. The PC carries out co-ordination and medical functions while the MFH is deploying
- A Mobile Field Hospital (MFH). Deployed at disaster sites providing co-ordination of MT's on disaster site, triage, reception, first aid treatment, conditioning for transportation, management of victim evacuation, medical expertise for patients through access to external medical databases or videoconferences between MFH's and RH's. Management of medical data. The MFH is equipped with medical means, databases and telecommunication systems.
- A Reference Hospital (RH). Located in a region or foreign country and acts as a medical knowledge centre for the MFH providing further medical expertise, triage and medical treatment, by interactive telemedical services. Healthcare services of the MFH are improved by: tele-services, telemedical and databases applications installed at both sites, in MFH and RH: Collaborative Platform tool for the videoconferencing, on-line telediagnosis and off-line telediagnosis Winvicos application. Beside the videoconferencing, it allows advanced telemedical services as interactive live teleconsultation, interactive telepathology, interactive intraoperative simulation.

A database gathers and manages all victim data coming from the different sites. The process of replication keeps these coherent between the 2 sites.

Satellite Telecommunication Systems. Allows the exchange of voice and data between the various sites and has been adapted to the data volume to be transmitted. For the present experiment:

Voice and data communication between the mobile teams and the PC are performed with Globalstar system (low rate transmission).

Data transmission from PC to MFH are performed by Inmarsat M4 link (medium rate transmission) and the audio communications between PC and MFH are performed by Inmarsat Mini M link (low rate transmission).

Exchanges between the RH and MFH are performed using EUTELSAT communication system (very high rate transmission).

TOPCARE

The TOPCARE e-homecare platform is a modular, scalable and secure e-homecare platform, which serves for bringing co-operative healthcare to sick persons at home and which enables the supervision of homecare therapies by health care centres in many home health scenarios. The TOPCARE platform is a universal home-care platform, which can be adapted to various ambulatory scenarios with a limited effort. The TOPCARE Platform takes advantage of internet technologies and makes use of the internet itself to communicate medical data in a secure and trustful way between patients and their physicians and a telehealth centre

The client-server architecture of TOPCARE comprises a so-called Telehealth Server with a central database, which contains all patient records. Access to this central data base is given to authorized health professionals by a Web Server with middle-ware components over a LAN connection for in-house access as well as over WAN connection for external access (e.g. over the Internet) using the SSL protocol (Secure Socket Layer) to guarantee data security in both cases. The content of the health record is presented as dynamic Web pages in a standard browser environment.

TeLeCare

TeLeCare solution enables remote nursing visits and vital sign monitoring through fully interactive voice, video and data transmission, and will target healthcare service delivery in rural and remote areas.

This solution is unique in that the targeted operators/users of this system are home-care nurses and their patients, therefore careful application of advanced technologies must be considered in the development and design. Successful adoption of this type of solution will be very dependent on the ability to deliver a user-friendly, seamless, end-to-end solution, that provides both economical value and enhances the ability of caregivers to deliver health care to their patient base.

The research and development effort will focus on development of the web-based software application, the communications interface that will allow the solution to be deployed over

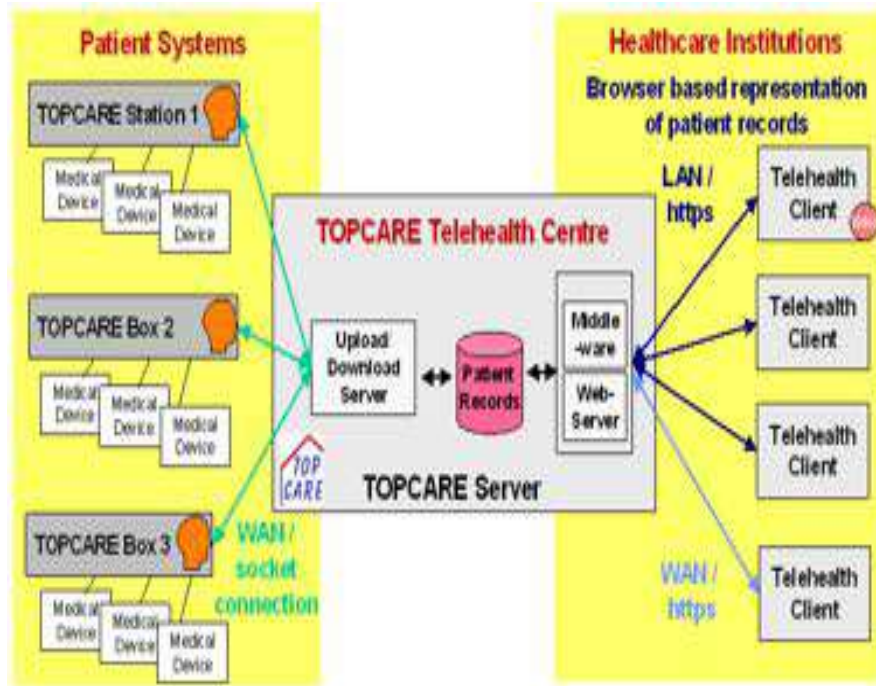


Figure 2.7: Overall architecture of the TOPCARE platform



Figure 2.8: The health professional interface. The browser-based representation of the electronic health record of a patient shows a trend curve for blood pressure readings in a homecare scenario

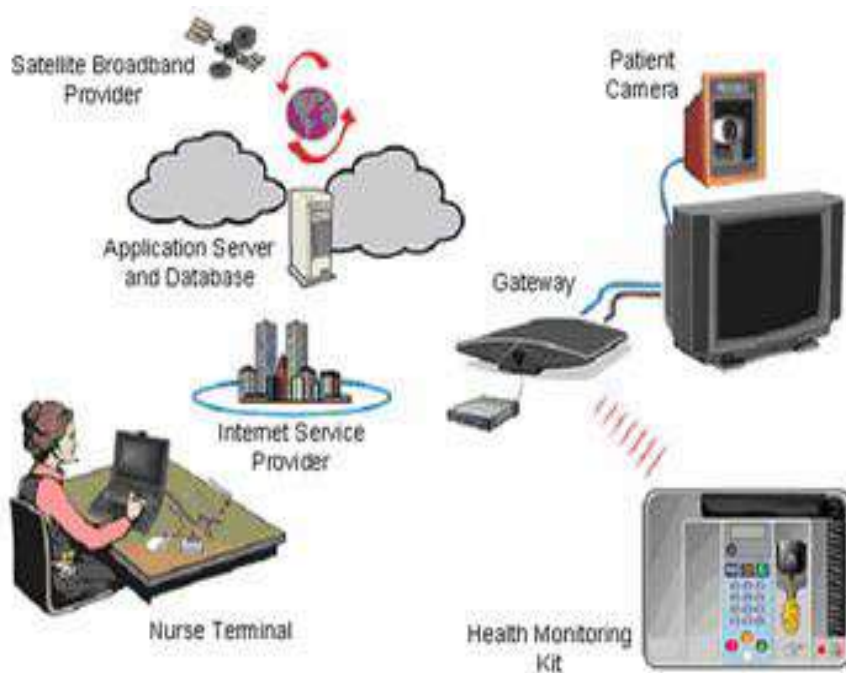


Figure 2.9: TeLeCare system overview

two-way satellite, and extension of the health monitoring kit (patient terminal) to support broader disease management capabilities as a strategic business direction for the solution as a whole.

The solution architecture is centered on a hosted application. Nurse and patient terminals access the network application server (NAS) directly and can be connected in a peer-to-peer fashion for a remote visit or e-learning application.

The TeLeCare system is fundamentally an IP-based solution and impacts all aspects of the design. Open standards are leveraged across the solution elements to support interoperability with third party products and applications, to increase functionality by allowing solution elements to be redeployed in different configurations, and to improve security, maintenance, and scalability. The benefits of making the solution IP standards compliant touch all aspects of the design, from universal broadband support, to the J2EE based network-hosted application.

CHILI - Digital Radiology

CHILI is a suite of software components for radiology and other fields of medicine involving image processing such as cardiology and pathology. The key characteristics are:

- Uses universal protocols (e.g. DICOM, CHILI, ftp, scp, DICOM e-mail)
- Automatic conversion between protocols
- Automatic routing depending on various parameters (including port, AET, day of the week, time, DICOM fields)

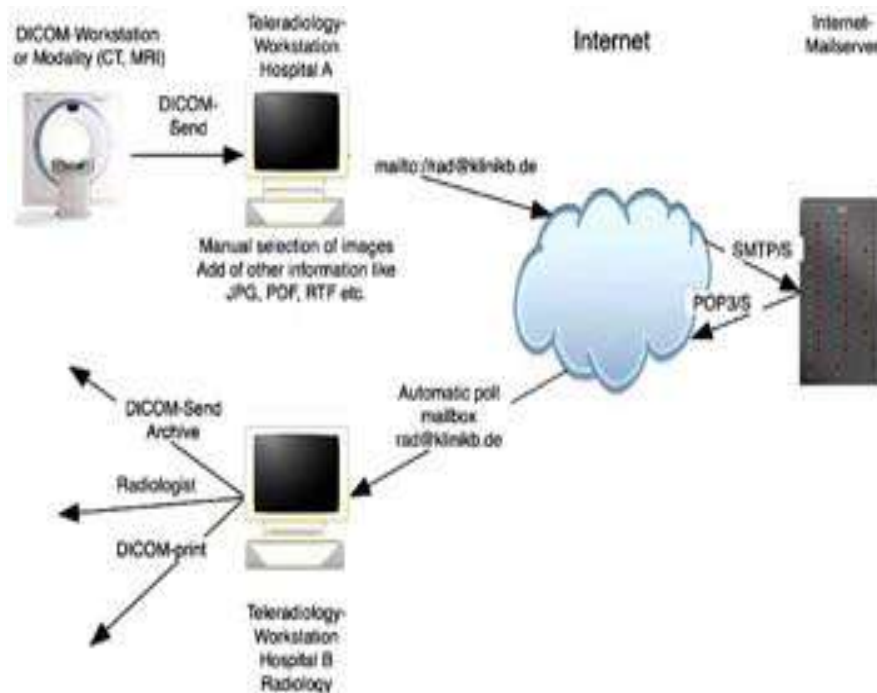


Figure 2.10: CHILI communication schema making use of e-mail

- Fault-tolerant, with automatic resumption after interruption
- Extensive security concept according to BSI recommendations
- Various encryption options available
- Backed up log files to record data transmission activity
- Can be integrated into any PACS or DICOM modality

The DICOM-e-mail protocol is a flexible and powerful protocol that can be used for a variety of teleradiology applications. It can meet the conditions for emergency applications but is limited if synchronous applications like teleconferences are needed.

E-mail is one of the most important internet services. Leading e-mail service providers report more than 100 million users each. E-mail is platform independent, easy to use and serves an excellent interoperability. Therefore it is frequently used for communication in the medical community and most physicians have access to e-mail communication. In many cases e-mail communication is the only way to transfer digital data between hospitals without media exchange. In most institutions e-mail traffic is checked to prevent the transport of malicious content into the internal networks.

The DICOM protocol (see also ANNEX) is the de facto communication standard for the transfer of biomedical diagnostic and therapeutic information between modalities and information systems inside a hospital. The DICOM Supplement 54, published in 2002, and the registered DICOM MIME type allow the transfer of DICOM objects using standard e-mail transport mechanisms.

The combination of such e-mails with additional encryption according to the OpenPGP standard is referred to as DICOM-e-mail.

However, this implementation supports **only the store-and-forward** communication method.

DicomWorks

Within DicomWorks is a secured teleradiology solution tailored for e-mail teleradiology applications at lowcost. Data processing consists of creating a couple of files with an encrypted and compressed image archive and a 128 bits decoding key file. No proprietary file format or encryption scheme is used. Files are exchanged using the e-mail (SMTP and POP) protocols, but FTP or sFTP can be used for better performances. Transmitting data through the Internet has many advantages such as an unrivalled ubiquity, simplicity and a constantly increasing data transfer rate at the lowest cost, but also many drawbacks, the first being the fact that data is not directly transmitted to the remote recipient, and may be stored, archived or intercepted in numerous places. For medical images and confidential patient data, there is therefore an important risk of security breach. New protocols such as IPSec, IPv6, standard updates (part 15 of the DICOM standard), private/public key architecture, tunnelling and other virtual private network (VPN) technologies are technical solutions to this issue, but remain difficult to install and use, unavailable or expensive. They are usually used by teleradiology professionals, but in practice, the only tools available for a majority of radiologists who just occasionally need to send images to colleagues or home are standard desktop encrypting tools (PGP). In a recent study, we presented a low-cost DICOM viewing and teleradiology application titled *DicomWorks*. This application allows radiologists to share images using email or client/server technologies. This widely distributed application (more than 43000 registered users to date) provides simple tools for sending anonymized images (masking, DICOM tags anonymization), but a quick survey of in-the-field practices shows that most of the DICOM images transmitted between radiologists are unaltered, because anonymization steps are time-consuming and there is a fear that they lead to erroneous patient identification. If anonymized, images are generally converted to plain JPEG, which implies a consequent loss of usability (unsorted images, no windowing, no possible measurement) Therefore, it was for us a major concern to update the image transmission tools included in this application to provide tools for easily, but securely, transmitting unchanged DICOM images through the internet at no cost. Image archives can be sent either on a regular e-mail account, or on an intermediate FTP (File Transfer Protocol) or sFTP (SSH File Transfer Protocol) server. FTP is preferable for transmitting a complete study, whereas e-mail is the ideal protocol for a limited (<100) count of images (e.g : one or two MR series, a thick reformatted CT series). The sending process is simple, as the user is only prompted to choose a deposit method (email or FTP data repository), the recipient's e-mail address and eventually a FTP or sFTP data repository server. With FTP, the archive is transferred as a single file into a remote directory, but for an e-mail repository, the archive can optionally be split in multiple fragments of fixed size (e.g.: 10 Mb) to avoid a potential attachment refusal from the server due to a too large attachment. The archive (or its multiple fragments) is sent as a regular MIME attachment. We implemented e-mail and FTP I/O using embedded tools, and sFTP using pSFTP (Putty secure file transfer protocol), an open-source command-line utility.

In a second step, the key file is sent to the same or to another e-mail address. This file

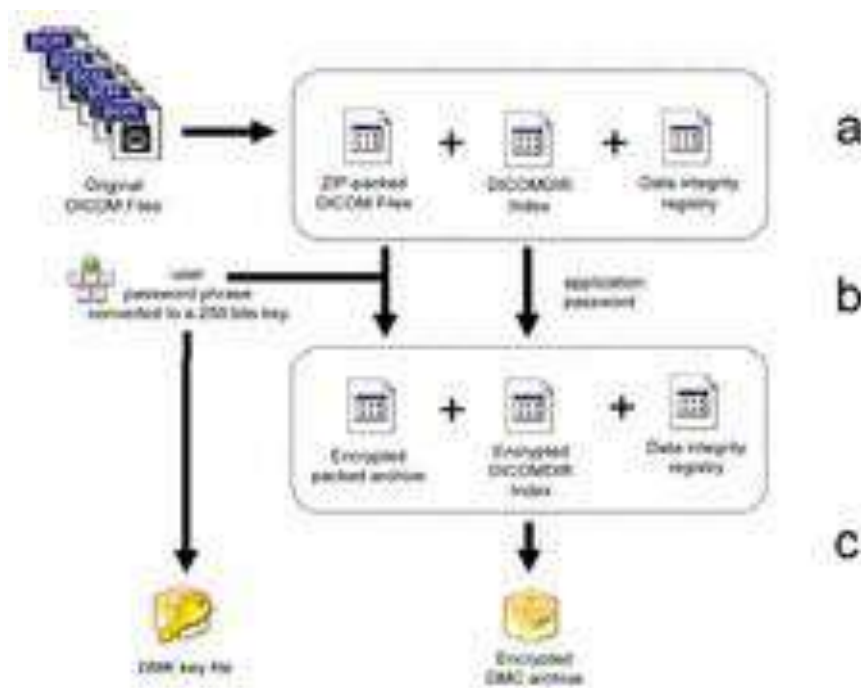


Figure 2.11: DicomWorks overview

contains the 128 bits MD5 hash-key corresponding to the original password phrase, and basic information on the image archive address (either an e-mail account or a FTP server).

TeleInViVo

My medical imaging collaboration application is composed of a number of single components that are working together: imaging module, database module, and the communication module. Figure 2.12 depicts the modules of the applications and the interconnectivity. The platform can be used for range of medical applications and particularly for teleradiology. The application is able to handle any type of imaging modality. Flexibility is provided through the modular design of the application.

Each component can run as an independent process on a personal computer (PC). The components are:

- **Imaging module:** It is a combination of DICOM 2D and 3D viewer, imaging filters, measuring, and annotation tools. Mainly used for medical imaging visualization and rendering
- **Image acquisition module:** Depending on the imaging modality, it can directly retrieve medical images from the medical devices. For example, the acquisition module uses a video frame grabber to catch all the frames delivered by an ultrasound device. In case of DICOM-enabled device, the acquisition module exchanges medical images via DICOM protocol over TCP/IP layer

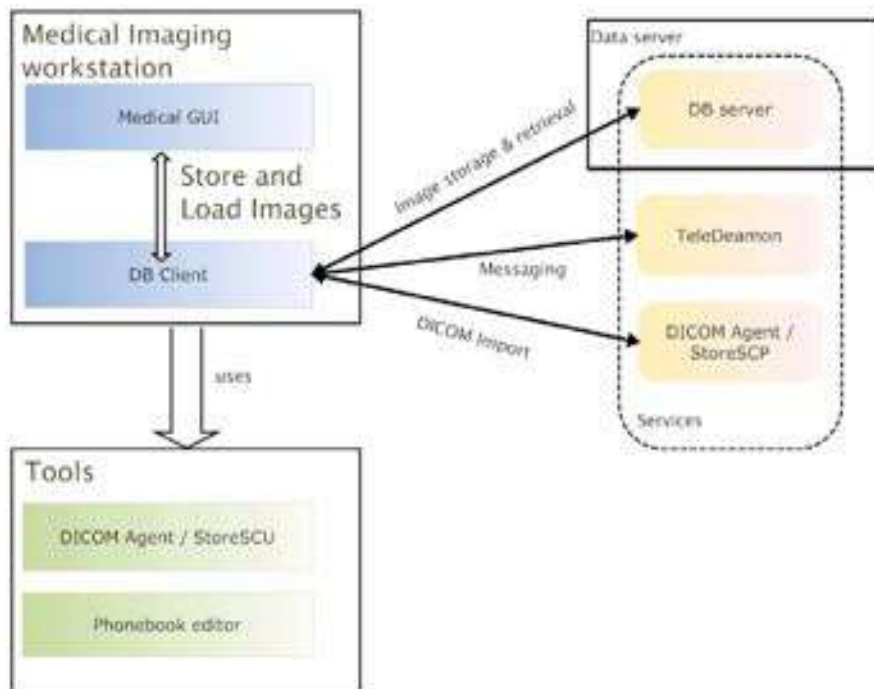


Figure 2.12: System architecture of medical imaging collaboration application

- Database module: It provides all the necessary interfaces for storing and retrieving of patient information, related to the study of medical images and vital signs from/to the medical database
- Communication/telematic module: It is the gateway to transmit and receive medical and non-medical information over secure tunnels

The user interface of the medical imaging module is shown in Figure 2.13, is the main application of the imaging system.

The largest part of the user interface is used for the display of the images. On the left side of the software all images currently loaded into medical imaging application are listed, as shown in Figure 2.14. In the center of the user interface, there is place for showing the details of one or more images.

Telematics/ Interactive Communication

The pre-existing version of the medical imaging collaboration application is able to exchange messages over TCP/IP layer. Both on-line and off-line communication was supported. A so-called TeleDamon application that is an NT service was used to send and receive off-line messages from one workstation (user) to another. TeleDaemon run on each workstation and prerequisite for exchanging messages is that the service is running all the time and the two workstation can directly be accessed over TCP layer.

The TeleDamon communicates with the database client or the database server for the sending and receiving messages. After a message has been received or sent is stored into the database.

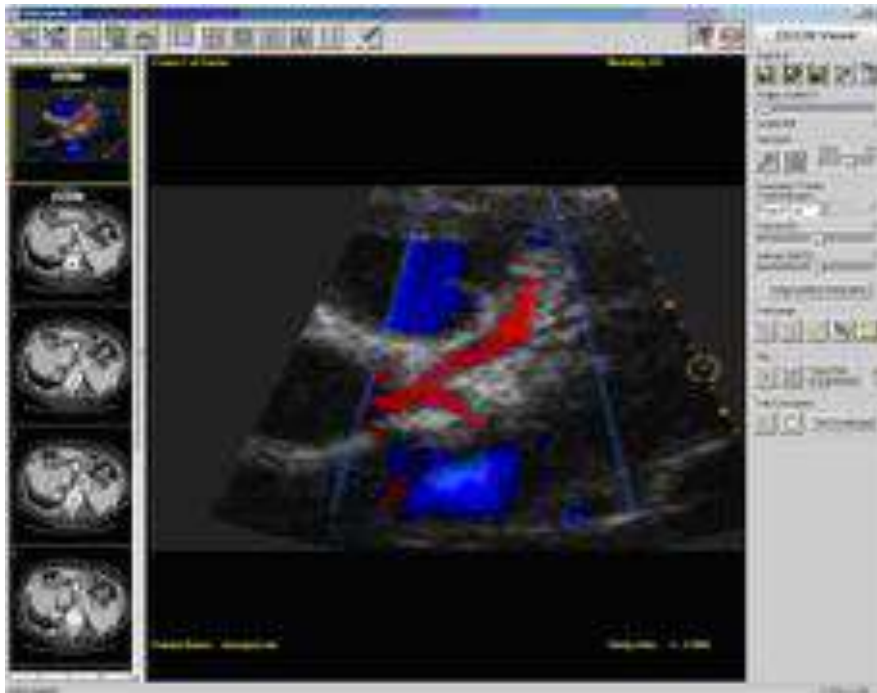


Figure 2.13: Graphical user interface of the medical imaging application

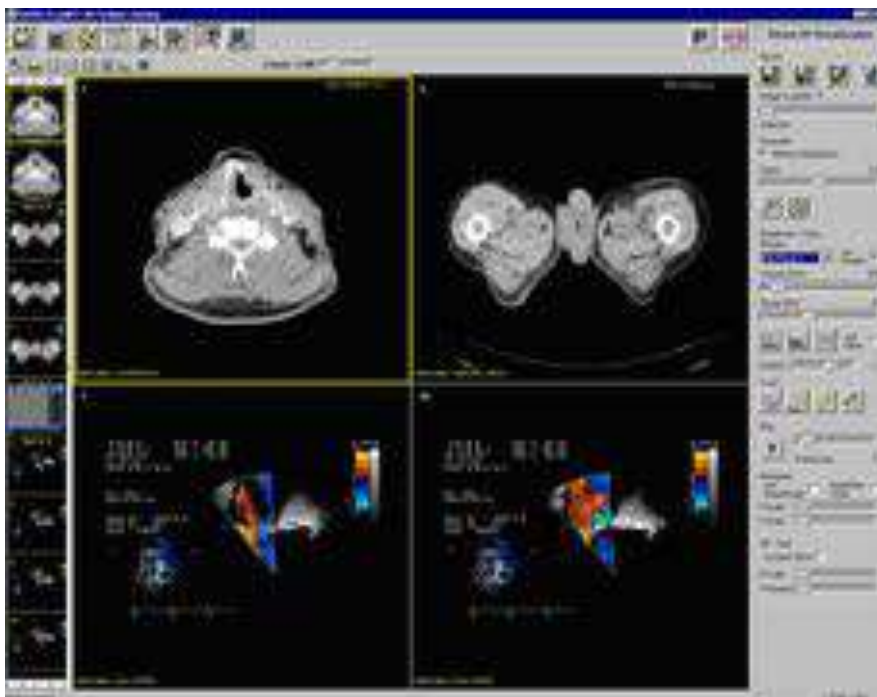


Figure 2.14: 2x2 view of the DICOM enabled viewer

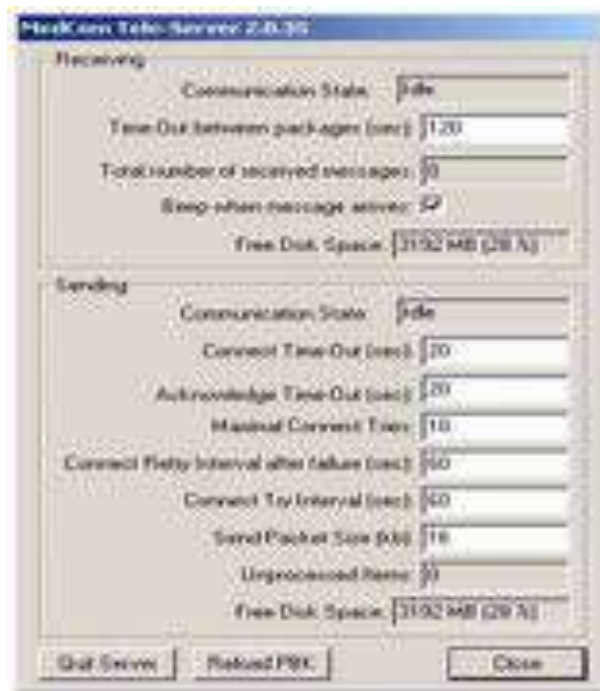


Figure 2.15: TeleDamon user interface

Figure 2.15 shows the graphical user interface of the TeleDamon. This user interface allows configuring some timeouts for the message transfer and displays statistics concerning the transfer of the messages.

2.5 Data types and volumes

Conducting telemedicine transactions in real-time implies that two parties exchanging information are simultaneously present and communicating interactively. The simultaneous exchange of information could be facilitated via a telephone conversation or could involve video including interview and examination of the patient, imaging of various anatomic sites, auscultation of heart and lung sounds, review of x-ray (CT, MRI, PER, ultrasound) examinations.

The alternative to real-time transaction is to conduct telemedicine transactions in store-and-forward mode whereby a package of medical information is compiled (stored) and sent (forwarded) to the intended consultant or expert medical officer for review and interpretation at his/her convenience.

The medical information compiled and sent may be as simple as a paper ECG or may be a combination of still frame images (x-rays), audio clips, video clips and patient medical records and other related examinations.

	Real-time	Store-and-forward
Interactive	Yes	No
Bandwidth requirement	Higher	Lower
Telecommunicaiton costs	Higher	Lower
Technology costs	Higher	Lower
Provides multimedia transmission	Yes	Yes
Response time	Immediate	Delayed
Impact on patient/consultant relationship	High	Low
Instructional potential for primary care providers	High	Low
Convenience of use for both providers	Lower	Higher
Ease of scheduling	Difficult	Unnecessary
Resembles face to face consult	Yes	No

Table 2.5: real-time vs. Store-and-forward communication

2.5.1 Communication pathways

In recent years several telemedicine applications have been implemented over wired communications technologies (plain telephone lines), ISDN and ADSL. However, nowadays modern technologies such as UMTS, GRPS, Edge as well as satellite communications and WLAN and Bluetooth, allow the operation of ambulatory and mobile telemedicine systems [58, 59].

In table 2.5.1 I summarized the available communication means used in mobile telemedicine applications.

GSM is in the standard mode of operation it provides data rates up to 9.6 kb/s. HSCSD techniques makes it possible to increase the data transmission up to 43.3 kb/s [60, 61].

The evolutions of mobile telecommunication systems from 2G to 2.5G (iDEN 64 Kb/s, GRPS 171 KB/s, EDGE 384 KB/s) systems provides the possibility of faster communication channels supporting the development of telemedicine applications that have demand for larger bandwidth [60].

Universal Mobile Telecommunications System (UMTS) is one of the third-generation (3G) cell phone technologies, which is also being developed into a 4G technology. Currently, the most common form of UMTS uses W-CDMA as the underlying air interface. It is standardized by the 3GPP, and is the European answer to the ITU IMT-2000 requirements for 3G cellular radio systems.

UMTS supports up to 14.0 Mbit/s (1.75Mb/s) data transfer rates in theory, although at the moment users in deployed networks can expect a transfer rate of up to 384 kbit/s for R99 handsets, and 3.6 Mbit/s for HSDPA handsets in the downlink connection [62, 63, 64].

In recent years other mobile network technologies such as WLAN have become popular and hot spots for accessing Internet have been deployed in almost every public place [60]. WLAN provides users with data rates up to 54Mb/s as long as the user is in the range of the access point.

Category	Type	Frequency band	Data transfer rates	Telemedicine applications
Wireless LAN	IEEE 802.11a	5 GHz	54 MB/s	Homecare and smart homes applications
	IEEE 802.11b	2.4 GHz	11 MB/s	In hospital patient telemonitoring
	IEEE 802.11g	2.4 GHz	54 MB/s	
	HIPERLAN 1	5 GHz	23.5 MB/s	Access to medical data in hospital environment
	HIPERLAN 2	5 GHz	54 MB/s	
	Bluetooth	2.5 GHz	1 MB/s	
HomeRF 1.0	2.4 GHz	2 MB/s		
	HomeRF 2.0	2.4 GHz	10 MB/s	
GSM	GSM-900	900 MHz	9.6-43 KB/s	Emergency telemedicine Patient telemonitoring in random locations
	GSM-1800	1800 MHz	9.6-43.3 KB/s	
	GSM-1900	1900 MHz	9.6-43.3. KB/s	
GRPS	GRPS	900 / 1800 / 1900 MHz	171.2 KB/s	
3G / UMTS	UMTS		2 MB/s	High bandwidth mobile telemedicine applications
Satellite	ICO	C,S band	2.4 KB/s	Location based telemedicine
	Globalstar	L,S,C band	7.2 KB/s	
	Iridium	L, Ka band	2.4 KB/s	High bandwidth telemedicine
	Cyberstar	Ku, Ka band	400 KB/s - 30 MB/s	
	Celestri	Ka band, 40-50 GHz	155 MB/s	
Teledesic	Ka band	16 KB/s - 64 MB/s	Regional healthcare network infrastructure	
Skybridge	Ku band	16 KB/s - 2 MB/s		
DVB	DVB-T	5/6/7/8 MHz	5-32MB/s (downlink)	
	DVB-H	5/6/7/8 MHz	10 MB/s (downlink)	
	DVB-RCS		8 MB/s (uplink)	

Table 2.6: Communication networks

Data type	Data size of typical examination
Digital blood pressure	1 Kb
Digital thermometer	< 2 Kb
Oxygen saturation meter	< 21 Kb
Electrocardiogram	< 141 Kb
Ultrasound	100 Kb - 2 Mb
Dermatology (high resolution and colour)	24-50MB
Scanned x-ray	2 - 4 MB
Mammogram	24 - 50 MB
CT (whole body)	58 - 164 MB
MR (whole body)	58 - 164 MB
PET (whole body)	12 MB
Video conference	< 600 MB
Patient's medical records	< 100 KB

Table 2.7: Required bandwidth for real-time transmission of medical data

In the US WLAN operates in two unlicensed bands:

- 802.11b and 802.11g operate in the 2.4 GHz band together with many other devices including Bluetooth [65, 66]
- 802.11a (Wi-Fi 5.2 GHz) operates in the 5.2 GHz which is relatively free of interference from other electrical devices operating in this band[67].

2.5.2 Size of medical data

The table 2.7 provides a rough estimation of the size of the medical data that may be involved in a telemedicine application. Here, I give typical data volumes. The figures would be higher or lower depending on the duration of the data acquisition as well as on the compression methods used for storage.

2.5.3 Bandwidth requirements

The range and complexity of telecommunication technology requirements vary with specific telemedicine application. Regarding the transmission of medical data there are no theoretical bandwidth requirements. Lack of bandwidth is interpreted as longer transmission time. However, in table 2.8, I have depicted the bandwidth needed for real time transmission.

2.6 Conclusions

In a tele-radiology application as equally in a home-care and emergency applications, the transportation methods of the medical data play an important role. A very common setup

Data type	Bandwidth required (for real-time transmission)
Digital blood pressure	< 10 Kb/s
Digital thermometer	< 10 Kb/s
Oxygen saturation meter	< 10 Kb/s
Electrocardiogram	< 15 Kb/s
Ultrasound	< 340 Kb/s
Dermatology (high resolution and colour)	< 680 Kb/s
Scanned x-ray	< 680 Kb/s
Mammogram	< 680 Kb/s
CT	< 680 Kb/s
Video conference	< 680 Kb/s

Table 2.8: Required bandwidth for real-time transmission of medical data

is the use of the TCP/IP protocol, enabling point-to-point among the clients. However, a point-to-point communication has a number of drawbacks, which make the use of it, and particularly the deployment of the application and use in real environment, almost impossible.

Avoiding this diversity of the protocol, I introduced the instant messaging protocol for serving all types of medical applications (home-care, emergency and radiology) and establishing a communication framework for telemedicine applications. In addition an instant messaging provides a number of useful features (i.e. presence status) that makes tele-collaboration more easier.

Instant Messaging is a fast, message-oriented form of communication. Different from e-mail, the user has the possibility to send messages to recipients in real-time. Messages are going to be delivered quickest possible [68].

An Instant Messaging (IM) system is understood as an application implementing instant messaging, besides also an online presence. In order to make that diversion clear, the terminology is to be clearly defined at first place dealing with concrete IM protocols.

Online Presence provides information on the current availability of a person. Besides the information whether a person is online or not (offline) further subcategories like *not available* or *available* are supported. These categories can be provided with status texts specifying the present activity more precisely e.g. *important examination* or *presently on ward round*.

Instant messaging in combination with online presence offers the users a decisive advantage compared to traditional forms of communication: they can check the status of presence of the recipient before sending the message. It can be seen whether the recipient is able now to read the message [69].

Besides IM systems online presence is moving slowly in day-to-day applications [70, 71, 72, 73] and particularly comes into medical business [74, 75]. A prominent example is the Microsoft Office-Packet. The version Office 2007 contains presence functionality. A status indicator in the documents signalises whether contacts which are interested in particular documents are available right now [69].

In the IM market numerous IM protocols are available. These IM protocols are appropriate developments of particular companies. The specifications of the IM protocols are not

	e-mail	Instant messaging	Point-to-point communication
Presence	---	+++	---
User mobility	+	+++	---
Security	+	+++	+
Client configuration effort	-	---	+++
HTTP routing	---	+++	---
Directory and discovery services	---	+++	---

Table 2.9: Comparing instant messaging to P2P and E-mail communication

	ICQ	AOL	IRC	SIP	Skype	Jabber	P2P
Open protocol	---	---	+++	+++	---	+++	---
Presence support	+++	+++	++	+++	+++	+++	--
In band data transmission	---	---	---	---	---	+++	--
Out of band data transmission	+++	+++	+++	---	+++	+++	--
Smart communication routing (S2S)	---	---	--	+	+++	+++	---
Ease to extend	---	---	---	--	---	+++	+
Secure communication	---	---	---	--	--	+++	+
Firewall / NAT capable	-	-	--	--	+++	+++	---
Intermedia server messaging storage	---	---	---	---	++	+++	---
User mobility	+++	+++	++	+++	+++	+++	---
Configuration effort	+	+	+	+	---	---	+++

Table 2.10: Comparison of instant messaging protocols

disclosed by the developing companies. Many protocol details were identified by the developers only by research of the protocols (Reverse-Engineering). Thus, it is in many cases possible to make alternative implementation, but however is often not desired. In Germany ICQ, in the USA AIM is widely spread [76]. More information are given in the Annex.

The proprietary protocols such as ICQ, AOL, Skype are relatively unknown due to missing official protocol specifications of the producer. Therefore, they cannot be implemented and extended to a desire level. An extension of the protocols might not be possible in many cases.

Over the last few years, the Internet community has been skeptical about proprietary protocols and does not support that concept. Protocols with specifications freely available gain ground and are preferable. Further on the protocols can be adjusted to special requirements by extensions.

The IRC-protocol allows the construction of a self-decentralized IRC-net. The transmission of data can be done via the DCC-protocol. A TCP-direct connection however is necessary which can not be done in all cases due to possible firewall barriers. In addition messages for a user in the off line mode are normally not stored.

I have chosen the jabber protocol for many reasons. Firstly, it is an open source protocols, widely implemented and supported by many groups and secondly, to support the mobility of the medical doctors, who use different terminal inside and outside the hospital.

The necessity for jabber data transmission protocols result from the XMPP protocol build-up. Hereby data are sent in small XML fragments. XML and therefore also XMPP is not suitable to transfer data in binary form [77]. If binary data needs to be transferred within an XML document, it has to be encoded into text, in advance, and finally to be encapsulated into the XML document.

Otherwise the binary data has to be transferred separated from the XML document, using

alternative TCP/IP and client-to-client connections. For transmission of binary data special jabber protocols and processes have been developed and published as JEPs (jabber extension protocols). The following chapter 3 deals with some of these extension protocols.

Chapter 3

Integrated protocols for data and imaging exchange

3.1 Introduction

Nowadays, the applications of telemedicine use internet and, in extension, TCP/IP protocol for data transmission and reception. Additionally, the data exchange may be done in one of two methods:

- Real-time or
- Store-and-forward.

The medical data can include medical images, vital signs, text, and sounds. Vital signs and text include ECG results (heart tracings), lab results and patient records. Medical images range from still photographs to full motion imagery. Radiological images, slides and graphics may be transmitted, as well as voice and chest sounds.

Telemedicine applications are making use of direct point-to-point communication, and therefore face problems with the communication when an end point is behind firewalls or private networks or even with user mobility. In this section I will depict an extension of the Jabber protocol, an instant messaging protocol, supporting binary data transmission for real-time and store-and-forward medical applications.

As I mentioned in the previous chapter there are diversions of transportation protocol for each type of application. Here, I introduce the Jabber protocol - Instant Messaging protocol - that can be used for all types of telemedicine applications. In this way I overcome problems of appropriately implementing communication protocol for data and imaging communication.

Jabber

Many different chat protocols are in use, but Jabber seems to be one of the most interesting. According to [78] and [79], Jabber is an open, XML-based instant messaging and presence

protocol. Besides chatting, the on-line status of particular user, is visible to others, which addresses availability awareness again.

Jabber was accepted by the IETF under the name XMPP, see RFC3920. It supports private networks as well as global public networks. Server gateways enable connections with other protocols such as ICQ and AIM, while the clients are still connected to a Jabber server only.

Since most firewalls only permit outgoing connections, Jabber uses a technique called HTTP Polling. The description below is quoted from [78]:

HTTP Polling essentially implies messages stored on a server-side database being fetched (and posted) regularly by a Jabber client by way of HTTP get/post messages. Since the client uses HTTP, most (if not all) firewalls would allow the client to fetch and post messages without any hinderance. Thus, in scenarios where TCP based direct connection is not possible, clients can use HTTP polling to stay connected and provide instant messaging. This aspect of Jabber protocol has also made it popular amongst a large user-base.

This makes Jabber quite handy and together with SSL/TLS secure as well. In combination with integrated systems, such protocols open a huge amount of possibilities. Users can see the availability of other users and even chat with them at every time. If the protocol is server based, a whole message history can be stored. Besides chatting between users, the server can also send messages on various events.

In the following, we will have a closer look at the Jabber/XMPP protocol. We are going to depict important aspects for further comprehension.

Addressing of XMPP packets [80] is done over Jabber identification (JID). Through this JID a recipient in the Jabber network can be clearly addressed. A JID thereby consists of the three components: node, domain and resource. The construction is:

node@domain/resource

Node Identifier is an optional component of JID. The Node Identifier is before the domain and is separated by the *@-sign*. Normally it is used for Jabber entities such as user names or chat rooms. An example for that: *isachpaz*

Domain Identifier is the only necessary component of JID. It is essential for the routing of the messages. Over the Domain Identifier a Jabber server is addressed. It consists of an IP address or a DNS name. In this example the Node Identifier: *isachpaz* could be completed by:

isachpaz@amazon-telemed.org

Resource Identifier, an optional component of a JID, is located behind the domain and is separated by the *'/'* symbol and represents a connection. The user has the possibility to connect several times with the same user name to a server. The single connections can explicitly be addressed over the Resource Identifier. In practice, a JID could look like this:

isachpaz@amazon-telemed.org/hospital.

The fundamental structure of the protocol consists of three stanza types:

- **message-stanzas** are units for information transmission, e.g. for chat- or data messages.
- **presence-stanzas** can be treated as a kind of *simple distributor*, especially for the online-presence status. A user can be informed over presence changes of others. At the same time this user can inform others about his/her own status.
- **IQ-stanzas** (Info and Query) serve as exchange of administrative queries and tax information [80] ; e.g. add a new user to the contact list, query of time or registration at the server with user name and password.

For each exchanged packet one of the three stanza types is used. A stanza is a little part of a XML document. The stanzas can be extended by XML name spaces. Thus, additional protocols (JEPs) are possible.

Furthermore, all stanzas have elemental attributes like the *'to'*-and *'from'*-attribute respectively with which recipient and sender respectively, are mentioned. Over the *'type'*-attribute a message type can be specified, e.g. a message contains an error notice.

Base64 basics

Email was originally destined only for transport of 7-Bit ASCII encoded text messages [81]. As computer applications, images and other data are mostly available as 8-bit binary, they cannot just be sent via email. Before sending them, they have to be converted into the ASCII format. For that purpose every binary zero could be shown as text '0', every binary one as text '1'. This would be very extravagant and extends data in size in an unnecessary way [81].

A more space-saving procedure is the Base64 encoding (RFC algorithm, described in [82]). Hereby, 8-bit binary data are converted into 6 bit text. The encoded data are as a result about 33% greater than the original, non-encoded source data.

The base64 uses an alphabet consisting of $2^6 = 64$ signs. Therein contained are the capital letters A to Z, the lower case letters a-z, the numbers 0-9 as well as the signs + and /.

Opposite to other algorithms, like Base85 or uuencode, Base64 offers the advantage that the used signs are shown alike in all ISO-646 character set sign and in all EBCDIC-versions [82]. That offers advantages when exchanging email attachments in a network of heterogeneous computer architectures.

The base64 encoding is shown in an example. As starting point the ASCII string *'Man'* is chosen. This string is shown in binary form at first. Later the single bytes are divided in signs of 6-bit each. The binary description of the string is specified in Table 3.1.

Encoded in ASCII, M, a, n are stored as the bytes 77, 97, 110, which are 01001101, 01100001, 01101110 in base 2. These three bytes are joined together in a 24 bit buffer producing 010011010110000101101110. Packs of 6 bits (6 bits has a maximum of 64 different binary values) are converted into 4 numbers ($24 = 6 \times 4$) which are then converted to their corresponding values in Base 64.

Text content	M				a				n														
ASCII	77				97				110														
Bit partner	0	1	0	1	1	0	1	0	1	1	0	0	0	0	1	0	1	1	0	1	1	1	0
Index	19				22				5				110										
Base64-Encoded	T				W				F				u										

Table 3.1: Translation ASCII string to Base64

In case the number of bytes is not divisible by three before encoding, fill bytes are added till a sum divisible by three is resulting. Therefore none, one or two fill bytes can be added. Each added fill byte is stated at the end of the Base64 string by the sign '='.

3.2 Binary transmission

In XMPP there are two different methods defined to manage a binary data stream:

1. in-band
2. out-of-band

Both are described below.

3.2.1 Out-Of-Band data transmission

In this method a separate connection is made for the binary data transfer. The clients themselves have to negotiate a working data stream/connection by sending each other their IP-addresses or the address of a proxy which is capable of connecting the partners together.

This method carries added complexity when firewalls are involved between the sender and receiver. This can be minimized by using a proxy server, which also adds a layer of anonymity as the sender and the receiver do not need to know each other's IP-addresses.

The transfer speed may be faster with this method compared to In-Band-Data transmission. Throughput is generally limited only by the connection speed of the sender and receiver.

3.2.2 In-Band-Data Transmission

In this method the data is sent in pieces on the same XML connection used for chatting.

All traffic flows in line over the Jabber server(s) to which the sender and the receiver are connected. This creates additional load on the Jabber server(s), making it potentially difficult for some high-traffic servers to support. Furthermore, due to the in-line nature of this method, the transfer speed is often much slower than through a direct (Out-Of-Band) connection.

One advantage is a bit of anonymity between the sender and the receiver as only the server knows clients' IP-addresses. Furthermore, this method requires no special configuration on the client side, making the ability to send a file automatic among established peers.

A protocol for transmission of data within the Jabber network is presented In JEP-0047 [83]. Therefore no further communication channel is opened, but the already established Jabber connection is being used. JEP-0047 uses IQ stanzas for to control connection as well as Message stanzas for data transmission.

The JEP-0047 protocol is suitable for transmission of small amount of data. These can be small binary data for example, an online game. The protocol can be used for data transmission for instance, when a Socks5 transmission is not possible [83].

Connection Establishment over JEP-0047

In the following, an example of transmission procedure is given and the most important packet types of the JEP-0047 protocol are presented. Before the first data can be exchanged, a virtual connection has to be established, firstly.

For that purpose the initiator sends an initiation packet to the recipient. Such a packet is shown in Listing 3.1. The recipient then can confirm or refuse the initiation packet. In case of confirmation a simple IQ stanza with the IQ type *result* is sent to the initiator (Listing 3.2). In error case an IQ stanza with the IQ type *error* is generated and sent to the initiator.

If the initiator receives a confirmation packet, as shown in Listing 3.2, the data stream will be opened and henceforth data be transmitted.

```
<iq type='set' from='doctor1@jabber.clinicA.de/telemed' to='↔
  doctor2@jabber.clinicBb.de/telemed' id='inband_1'>
  <open sid='mySID' block-size='130' xmlns='http://jabber.org/↔
    protocol/ibb' />
</iq>
```

Listing 3.1: A JEP-0047-Initiation packet

```
<iq type='result' from='arzt1@jabber.klinik-a.de/telemed'
to='arzt2@jabber.klinik-b.de/telemed' id='inband_1' />
```

Listing 3.2: AA JEP-0047-Confirmation packet

Data Packets

During the data transmission, the data will be encoded into Base64 and be encapsulated in Message stanzas, as shown in Listing 3.3.

```
<message from='doctor1@jabber.clinicA.de/telemed' to='doctor2@jabber.↔
  clinicB.de/telemed'>
  <data xmlns='http://jabber.org/protocol/ibb' sid='mySID' seq='0'>
    qANQR1DBwU4DX7jmYZnncmUQB/9KuKBddzQH+tZ1ZywKK0yHKnq57kWq+↔
      RFtQdCJ
    WpdWpR0uQsuJe7+vh3NWN59/↔
      gTc5MD1X8dS9p0ovStmNcyLhxVgmqS8ZKhsblVeu==
  </data>
```

```
</message>
```

Listing 3.3: A JEP-0047-Data packet

Creating the transmission packages, a small amount of preprocessing time is needed. Large messages are divided into small messages. The size of the divided messages is given by the Initiation packet as shown in Listing 3.1. The size of such a block consisting of binary data is fixed in the initiation packet defined by the *blocksize*-attribute in bytes. In our given example, a block size of 130 bytes (3.1) means that a maximum 130 bytes of binary data can be put in a data packet.

In the next step, the data block will be encoded into Base64. Subsequently, the Base64 string (encoded data) is encapsulated into the *data* tag. Furthermore, the *data* tag has a sequence number. That is a 16 bit integer counter, which increments with every packet. If the counter reaches a maximum of 65535 it will be reset to 0 [83].

Connection Termination

When all data has been sent, the data stream can be closed again by a close packet. The close packet serves as connection control and is sent therefore within an IQ stanza. A *close* tag is attached to the IQ stanza. The receipt of the close packet is confirmed again by a confirmation packet (Listing 3.2).

Error Cases

In case of error the data stream closes and data already received are declared void. Such an error can occur, for instance, as soon as the initiator receives an error packet informing him that a data packet could not be delivered. The recipient can easily state, with the help of the sequence number of the data packets, if the data sequence has been interrupted by a missing packet. Furthermore, it is also possible that packets arrive in a wrong order. In this case also the data stream has to be closed and data are going to be declared void.

Application Instructions

A few application guidelines in the JEP-0047 protocol description can be found. Socks5 data transmission (out-of-band data transmission) should be preferred to the JEP-0047 data transmission in most cases. For the Socks5 data transmission no further encoding is necessary, whereby the amount of data to be transmitted is minimised and the transmission time is shortened.

In practice, it has been proved that only In-Bank-data transmission is applicable for medical applications, where most of the cases firewall rules permit no out-of-band data transmission [74].

On the other side, a Jabber server can bound the bandwidth of a connection. That depends on the size and frequency of incoming data packets. In addition, a server can disconnect the connection when too large packets are sent. As standard a block size of 4096 bytes is proposed.



Figure 3.1: URI-protocol communication

Conclusions

The Socks5 byte stream protocol, presented here, defined in JEP-0065, as well as the In Band Byte stream protocol, defined in JEP-0047, were specified for transfer of data streams.

The protocol specifications were kept generally on purpose as to the data to be transferred. Thus additional meta-data is necessary for the transmission of files.

It contains specifications such as *filesize*, *filename* or *time of last change*. Such meta-data for file transfer over Jabber byte stream protocols are defined in JEP-0096 [84]. By means of that extension, it is possible to transfer files with the byte stream protocols.

In general it is possible with all protocols presented here to exchange files between two Jabber entities, so also medical imaging data, such as X-ray, CTs, MRIs, PET images or ECG strips can be transmitted.

It is essential now to analyse the protocols as to the behaviour in networks with firewall systems. Thereby it is important that the protocol does not require any changes of the firewall configuration.

The URI-based transmission protocol presented in this chapter presumes external services for transmission (Figure 3.1), such as a Web or FTP server. Only URIs are transferred referring to such a service. How the protocol behaves behind a firewall depends strongly on the services used. Displaying an X-ray image to an expert physician, the physician would have to copy the images, for example, to a local web server and send the address of the image of this web server with the help of URI-protocol. For that purpose, medical image datasets need to be available on the web server, beforehand.

If the web server is running on the same computer as the tele-medical application, it is trivial as the connection cannot be blocked by an external firewall. If the web server however is running at another place, the connection can be blocked by firewalls. Also it is not always

guaranteed that the caller can always establish a connection.

It is not guaranteed that data can always be transferred with an existing Jabber connection [84]. Additionally, the publishing of data by an additional service is an extra effort as the data has to be protected against unauthorised access. Only the recipient of the data needs to have access to the data supplied.

The Socks5 byte stream protocol neither fulfills the requirements. For the data transmission an additional service also is necessary; such as a Socks5 proxy server. However, it requires a direct connection to the proxy server. In case, the connection to a Jabber server was made via a HTTP connection (**HTTP Polling**), due to the fact that the firewall configuration of the used network allows only HTTP connections, a data transmission would not be possible.

In Band Byte streams according to JEP-0047 do not require an additional connection and use the existing Jabber connection for data transmission. This kind of data transmission is reliable so far as it does not require an additional connection which could be blocked by firewall restrictions. The minimal requirement at HTTP Polling for a Jabber connection is the access to web sides over HTTP. Thus the data transmission is possible in most cases, if the user is able to navigate to the Internet with a web browser.

The disadvantages of the JEP-0047 protocol are the additional efforts of Base64. Due to the Base-64-Encoding data grow by 33.33%. The transmission becomes slower due to the greater amount of data. The protocol is nevertheless suitable for data transmission by the firewall stability. Thus the total concept exclusively reverts to this method of data transmission.

The requirement of data transmission of off-line entities is not handled by any protocol presented here. Therefore the procedure of In Band Byte stream chosen in the last step is extended by this functionality, as presented in the following section.

3.3 In-Band-Data protocol extension

If a Jabber entity is off-line, which means not registered at a Jabber server at the moment, the messages are normally stored on the server for late delivery. That applies only to message stanzas. The idea therefore is to send the data in form of such Message stanzas which can be stored at the server.

The In-Band-Data protocol (JEP-0047-Protocol) sends the data in the form of Message stanzas which can be stored on the server. For initiation of data transmission, IQ stanzas are used. These IQ stanzas are required for the interaction with the recipient. Enabling an off-line data transmission, these control packets have to be omitted. The data are sent without prior confirmation of the recipient. This bears a certain risk that data could be sent to the recipient, who does not want to receive.

Furthermore meta-data is sent in Message stanzas indicating the filename and the file size. These are also stored on the jabber server. The meta-data used in the same manner as proposed in JEP-0096 [84]. The only difference is that they are sent over Message stanzas for storage.

Data Packets

The real imaging data is sent as Base64 encoded in a data packet, similar to a JEP-0047-data packet (Listing 3.4). The *data* tag was put additionally into an *ibbDatatransfer* tag along with a *blocksize* property.

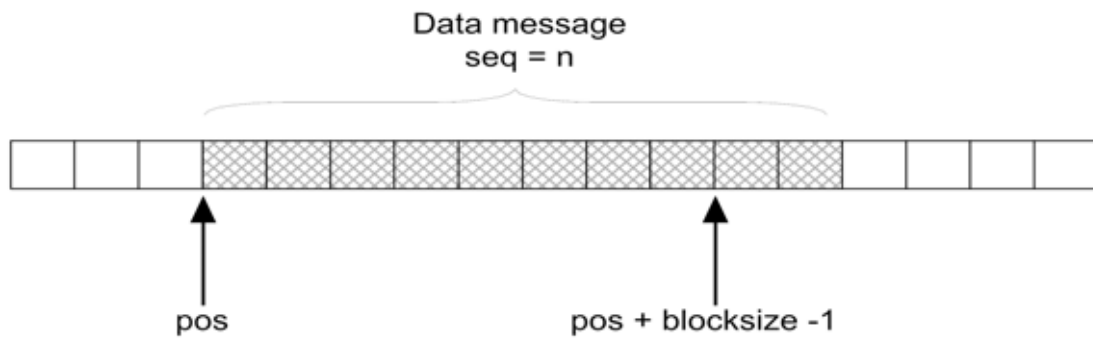


Figure 3.2: Data blocks

```

<message from='doctor1@jabber.clinicA.org/telemed' to='doctor2@jabber ↔
.clinicB.org/telemed'>
  <ibbDatatransfer sid='..'>
    <data seq='..' blocksize='..'>
      qANQR1DBwU4DX7jmYZnncmUQB==
    </data>
  </ibbDatatransfer>
</message>

```

Listing 3.4: An extended JEP-0047-data packet

A file is divided into n blocks of the size *blocksize* before the data transmission. That is shown in Figure 3.2. The position of the first byte in a packet can be found out by calculating $seq * blocksize$, whereby *seq* is a sequence number of the packet.

In case a sequence number is chosen for every packet and the above laws are considered in the implementation, the sequence of the packets arriving to the recipient is irrelevant. The data are always written at the right place, even when the sequence of the packets is totally disordered.

This is no additional work for the protocol, but it has only to be considered in the implementation. Even, when the right arrival sequence of the packets, processed by an XMPP-compatible server [80], is guaranteed, you are independent from possible errors at off-line storage.

Meta Data Packets

The meta-data packet supplies information to the recipient describing the file transmission. File name, the size of the file, as well as a description belong to the meta-data.

The *filesize* tag is of greatest importance for the recipient as he can find out with it when the receipt has been finished and if he has received all data. The *filename* tag serves as naming of the file received in the subsequent implementation.

```

<message from='doctor1@jabber.clinicA.org/telemed' to='doctor2@jabber ←
.clinicB.org/telemed'>
  <ibbDatatransfer sid='..'>
    <metadata>
      <filesize> Dateigroesse in Bytes </filesize>
      <filename> Dateiname </filename>
      <description> Beschreibung des Inhaltes ←
    </description>
    </metadata>
  </ibbDatatransfer>
</message>

```

Listing 3.5: A meta-data packet

Hash-Packet

In order that the recipient can check the correct transmission after receipt of the data, the sender generates a SHA1-Hash of the file to be sent. He transmits this during transmission to the recipient at any time.

```

<message from='doctor1@jabber.clinicA.org/telemed' to='doctor2@jabber ←
.clinicB.org/telemed' id='msg1'>
  <ibbDatatransfer sid='..'>
    <hash> SHA1-Hash </hash>
  </ibbDatatransfer>
</message>

```

Listing 3.6: A Hash-Packet

Confirmation Packets

In case the recipient has received all data and the hash- and meta-data packets, he also generates a hash value of the file received. If both hash values are identical, all data have been probably received correctly. The recipient puts the status of the confirmation packet to *ok*. In case of an error, like an unequal hash value for example, he puts an *'error'*. The confirmation packet can be sent to the sender now.

This packet is shown in Listing 3.7 as an example.

```

<message from='doctor1@jabber.clinicA.org/telemed' to='doctor2@jabber. ←
.clinicB.org/telemed'>
  <ibbDatatransfer sid='..'>
    <confirmation status='ok | error' />
  </ibbDatatransfer>
</message>

```

Listing 3.7: A confirmation packet

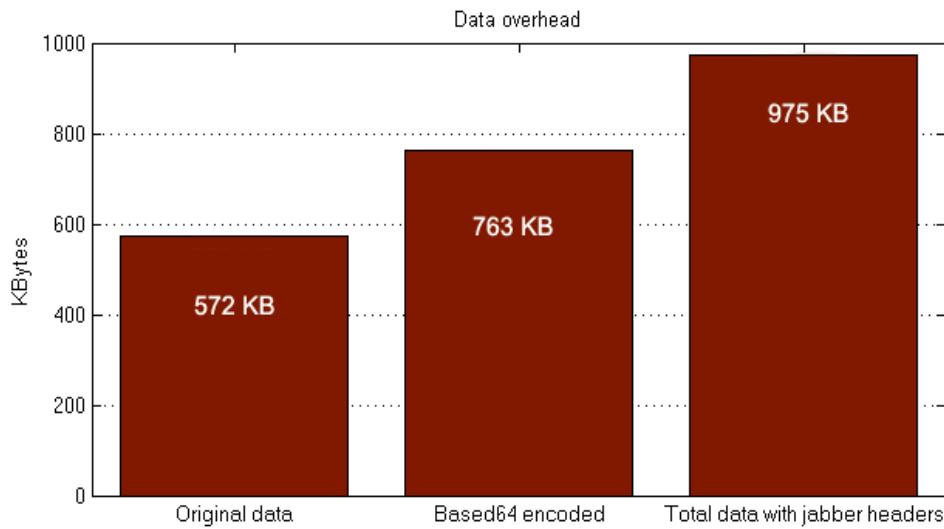


Figure 3.3: Graphic view of additional data transmission effort

End of the Receipt

The receipt ends for the recipient as soon as he has received all data, the meta data as well as the hash-packet. He states whether all data have arrived by comparing the size of the data already received with the *filesize* from the meta data packet.

Transmission Effort

The In-Band-data transmission produces additional data information in two places. Firstly, by the Base64-Encoding and secondly by the XML encapsulation of the jabber message. In Figure 3.3 the additional data information of an test transmission with 572 KB binary data is illustrated. Additionally, the size of transmitted packages is 512 bytes.

Before, the transmission, the initial binary data need to be encoded into base64. Those actions produce 33.33% more data, as it has been shown in section 3.1.

Later on, the encoded data need to be encapsulated into a jabber message, and additional XML data shows up.

As shown in Figure 3.3, the third column depicts the total data being transmitted over the transmission line. In that case, we have fragmented the encoded data into small packages of 512 bytes in size. Now a lot of packets are necessary to send the same data amount. The additional XML effort created by that leads to a new enlargement of the data amount.

The number of transferred bytes can be estimated with the equation (3.1).

$$f(n, b) = 1,33n + 150 \left\lceil \frac{n}{b} \right\rceil \quad n, b \in \mathbb{N} \quad (3.1)$$

The arguments of the equation are n and b , whereby ' n ' is the source size of the data and b is the block size of each packet.

For our calculations, we approximately use a size of 150 bytes for the XML data of the jabber headers. That amount varies in practice and depends on the length of the addresses (JIDs).

The additional data information through the XML presentation can be approximately calculated by the equation (3.2).

$$g(n, b) = \frac{150 * \lceil \frac{n}{b} \rceil}{n} \quad (3.2)$$

Treating that we have a very large amount of data ($n \rightarrow \infty$), we estimate the data overheads produced by the XML encapsulation. In Figure 3.4, I plot the equation (3.3)

$$\lim_{n \rightarrow \infty} g(b) = \lim_{n \rightarrow \infty} \left(\frac{150 * \lceil \frac{n}{b} \rceil}{n} \right) \quad (3.3)$$

From the equation (3.3), we conclude that as the block size of each packet, in which the original data is divided, the smaller additional data information is added by the XML encapsulation of the jabber messages. That is depicted by the Figure 3.4.

I need to mentioned that the data of the XML encapsulation is very large then small amount of binary data as well as small block size of b are in place. Summarizing, the increased amount of the transmitted data mainly produced by the Base64 encoding and not by the XML data encapsulation of the jabber messages.

3.4 On-line collaboration

In on-line collaboration, two or more doctors have the capability to communicate in real time with each other. During the on-line collaboration session, the doctors share the same user interface. The two remote user interfaces are synchronized by exchanging status application messages and mouse movement update messages.

Establishing and closing an on-line session

As initiator is the user, who has started the on-line collaboration session, and as receiver, the user who receives the request to participate to an on line collaboration session. An on line collaboration session (Figure 3.7) starts when the *initiator* sends an initiation message. The initiation message is given in Listing 3.8.

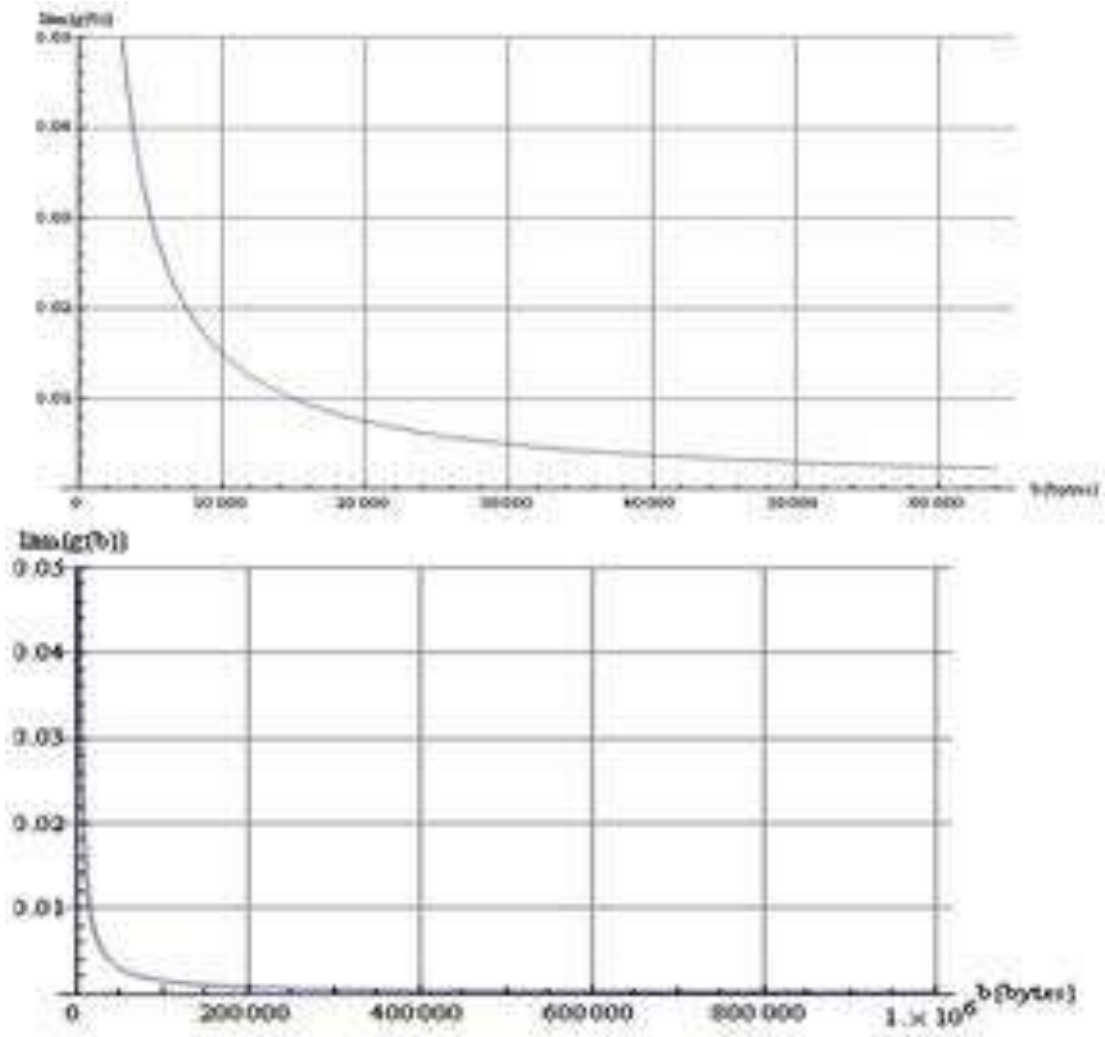


Figure 3.4: Plots of data overheads produced by the XML encapsulation, when $n \rightarrow \infty$ and b ranges from 0 to 1 MB

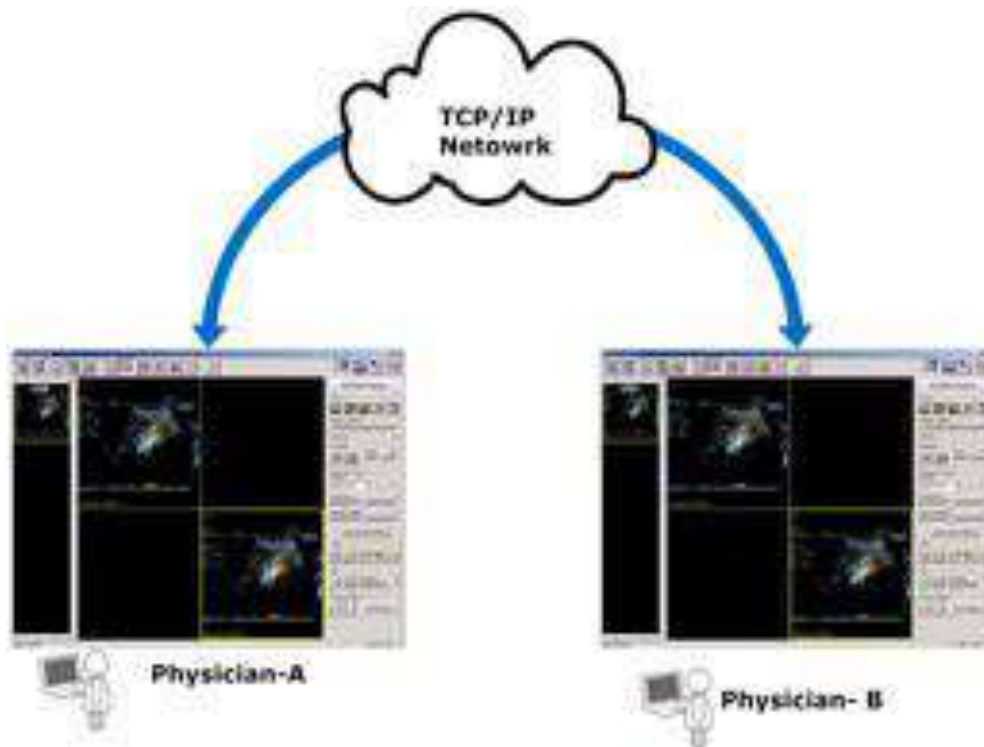


Figure 3.5: Doctors sharing the same user interface

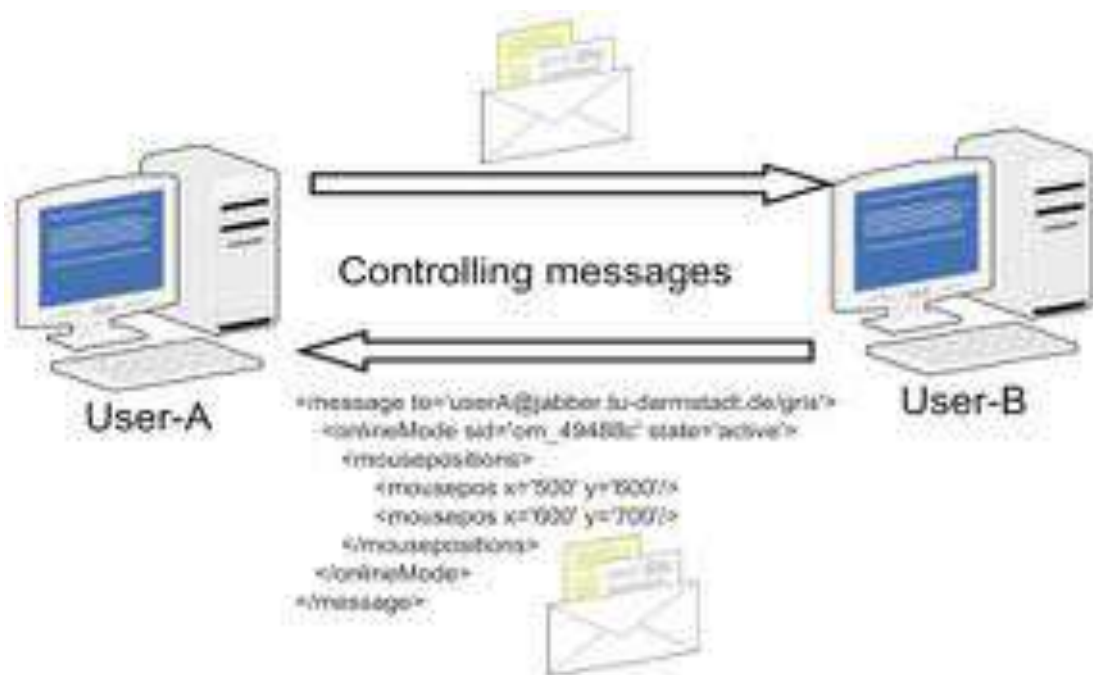


Figure 3.6: Controlling messages exchanged among users

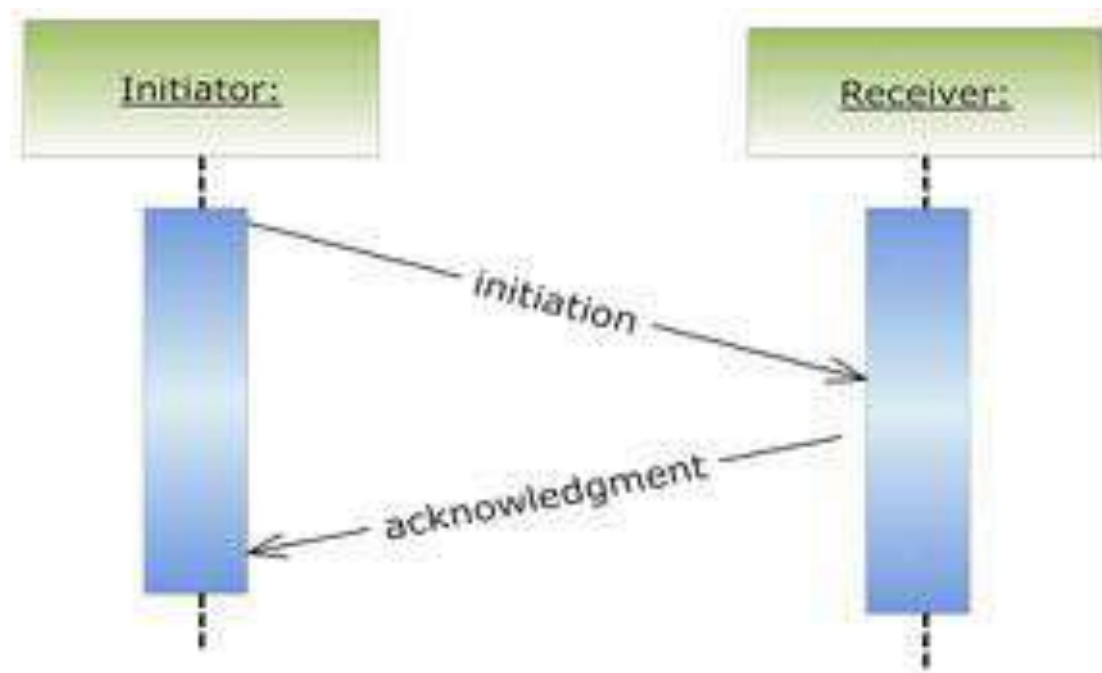


Figure 3.7: Establishing an on-line collaboration

```
<iq to='Receiver-JID' type='get'>
  <onlineMode sid='SessionID' state='initiation' />
</iq>
```

Listing 3.8: A initiation packet

As soon as the receiver gets the *initiation* packet, he has to reply with a *confirmation* packet (3.9). If the receiver does not accept the on-line collaboration, he needs to reply with the *closing* packet (Listing 3.10)

```
<iq to='Sender-JID' type='result'>
  <onlineMode sid=#SessionID' state='acknowledge' />
</iq>
```

Listing 3.9: Confirmation packet

```
<iq to='Receiver-JID' type='get'>
  <onlineMode sid='SessionID' state='initiation' />
</iq>
```

Listing 3.10: On-line collaboration closing packet

Finishing the collaboration session (Figure 3.8), the user needs to send the closing packet, as depicted in Listing 3.10

On-line session state diagram

In Figure 3.9, I depicted the state of the on-line collaboration process.

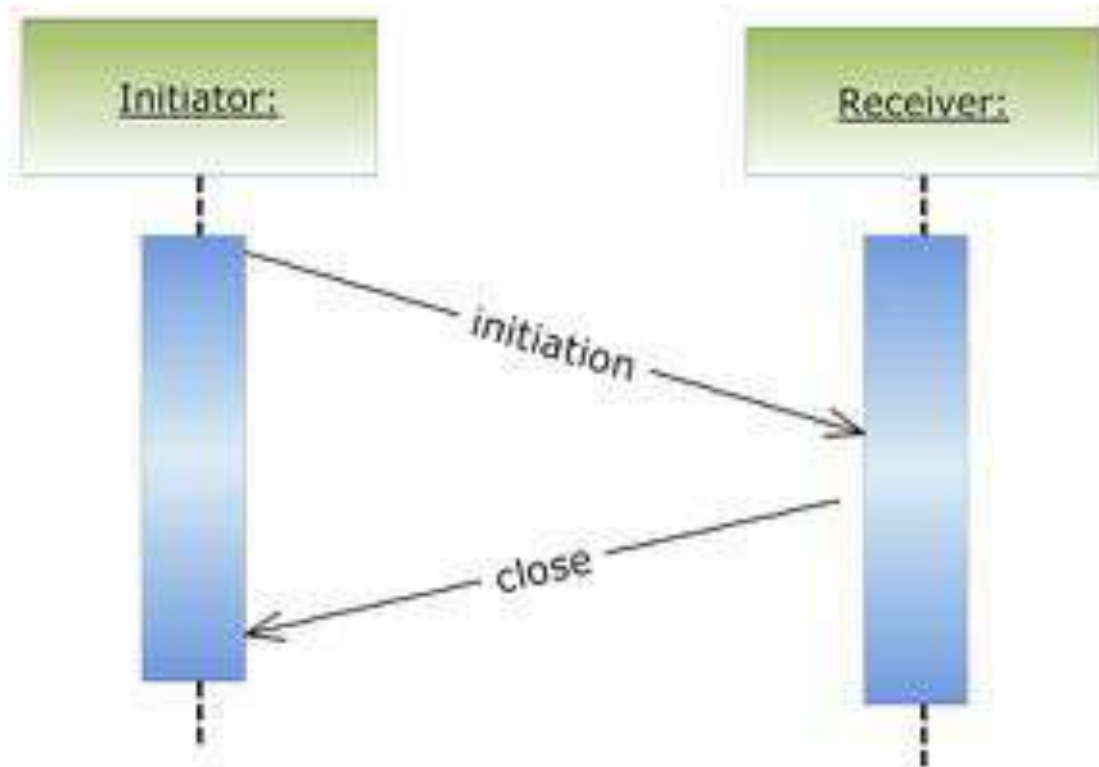


Figure 3.8: Shutdown an on-line collaboration

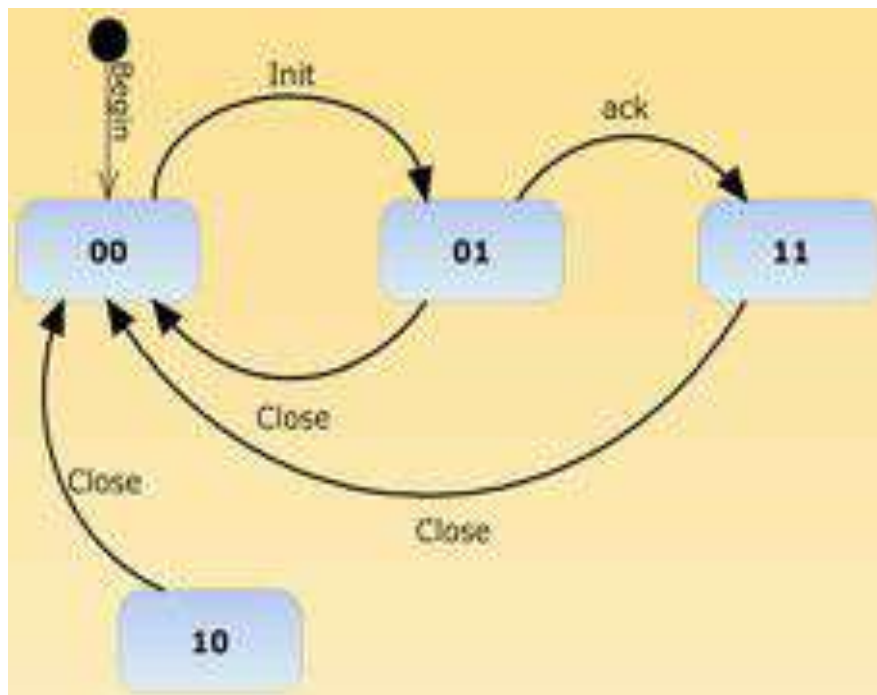


Figure 3.9: State diagram of on-line collaboration

The activation status consists of two coordinates x,y , where x refers to *initiator* and y refers to the *receiver*. The used schema is xy , where $x, y \in \{0, 1\}$

$$x,y = \begin{cases} 0 & ,inactivate \\ 1 & ,active \end{cases} \quad (3.4)$$

Through the transaction $\delta(00, init) = 01$ (acceptance of the initiation packet), is activated the on-line mode on the *receiver* side. Then the receiver sends the acknowledgment/confirmation packet to the *initiator* and now both ends turn into active on-line mode.

On-line session and bandwidth

For the estimation of the necessary bandwidth of the operation of the on-line mode, a sample of on-line message is given by Listing 3.11.

```
<message to='mike@jabber.amazon-med.net/TC'>
  <onlineMode sid='om_49488c' state='active'>
    <mousepositions>
      <mousepos x='500' y='600' />
    </mousepositions>
  </onlineMode>
</message>
```

Listing 3.11: On-line collaboration packet

The message in the Listing 3.11 is 165 bytes long. The adequate bandwidth for the transmission of the online messages is given by equation (3.5), where n is the number of the *mousepos* or *events* in each second, and g is the length of whole message in bytes. Finally, b is the necessary bandwidth in Kb per seconds (Kb/s).

$$b(Kb/s) = n * \frac{g(bytes)}{1024} \quad (3.5)$$

Illustrating the equation (3.5), for $g=165$ bytes, we see that as the number of the events per second increases, at the same time we need more bandwidth (Figure 3.10).

So, if we need to transmit $n=90$ events per second, we need a bandwidth of 12.89 KB/s.

Events grouping

The transmission effort can be reduced, by grouping the events need to be sent, as shown in Listing 3.12

```
<message to='mike@jabber.amazon-med.net/TC'>
  <onlineMode sid='om_49488c' state='active'>
    <mousepositions>
      <mousepos x='500' y='600' />
      <mousepos x='500' y='610' />
      <mousepos x='500' y='620' />
    </mousepositions>
  </onlineMode>
</message>
```

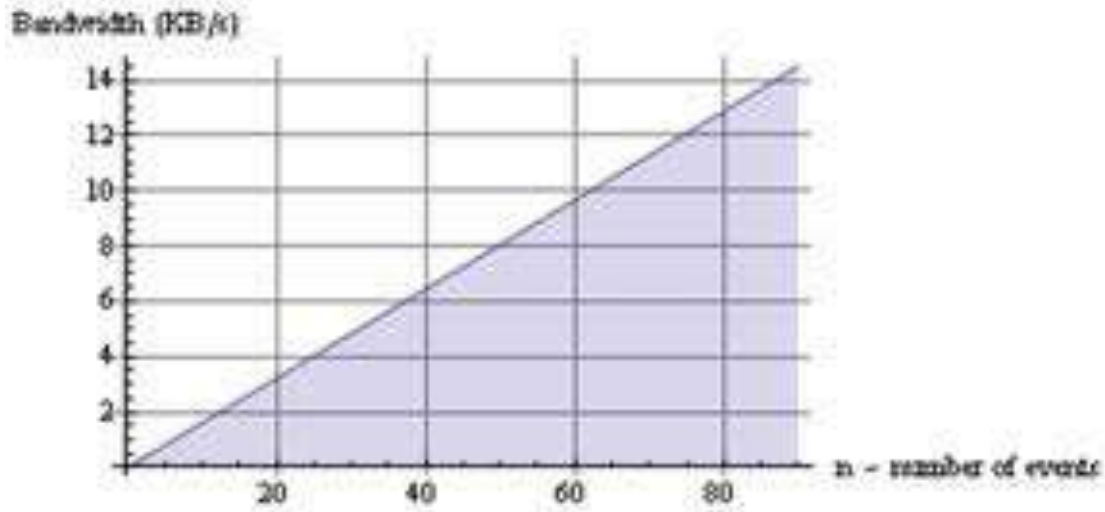


Figure 3.10: Bandwidth in conjunction with number of messages

```

<mousepos x='500' y='630' />
</mousepositions>
</onlineMode>
</message>

```

Listing 3.12: Event grouping

Calculating the needed bandwidth in KB/sec, we treat n as the number of the events, which will be transferred and γ the number of the events in each grouping. Now, the bandwidth equation is given by (3.6).

$$b(Kb/s) = \left\lceil \frac{n}{\gamma} \right\rceil * \frac{g(\gamma)}{1024} \quad (3.6)$$

$$g(\gamma) = 140 + 25 * \gamma$$

The equation $g(\gamma) = Length(Bodymessage) + \gamma * Length(eventmessage)$ gives the length of the individual messages, which are going to be transmitted. In that example we have the 140 bytes of the body message and 25 bytes the length of each message.

In Figure 3.11, we keep the number of events constant ($n=90$) and we calculated the bandwidth in conjunction with γ group size.

In addition, the Table 3.2 shows the necessary bandwidth for different groupings. You can see that the necessary bandwidth decreases per packet with a still growing number of positions. You have to consider however that a grouping leads to an increased latency as the recipient gets the packet only after a few positions. This leads to a less fluent movement of the mouse in the display mode.

3.5 Off-line collaboration

In off-line communication mode physicians are able to convey medical data at their convenient time. In off-line mode the transfer of medical information is not usually time

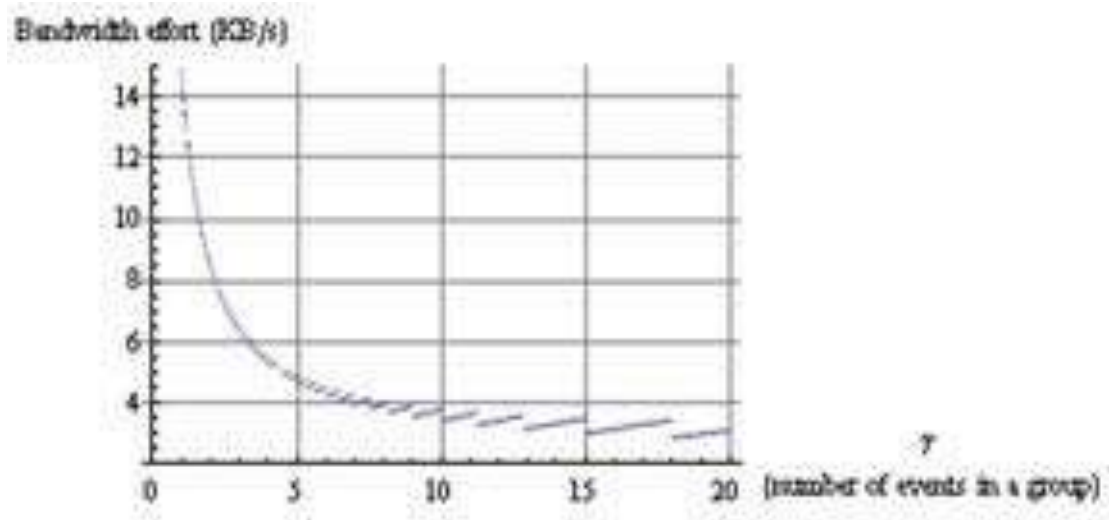


Figure 3.11: Bandwidth and grouping of events

Grouping (# of events)	Bandwidth
1	14.50
2	8.35
3	6.30
4	5.39
5	4.66
6	4.25
7	3.99
8	3.98
9	3.56
10	3.43
11	3.65
12	3.44
13	3.18
14	3.35
15	3.02
16	3.16
17	3.31
18	2.88
19	3.00
20	3.12
21	3.25
22	3.37
23	2.79
24	2.89
25	2.99
26	3.08
27	3.18

Table 3.2: Grouping and bandwidth

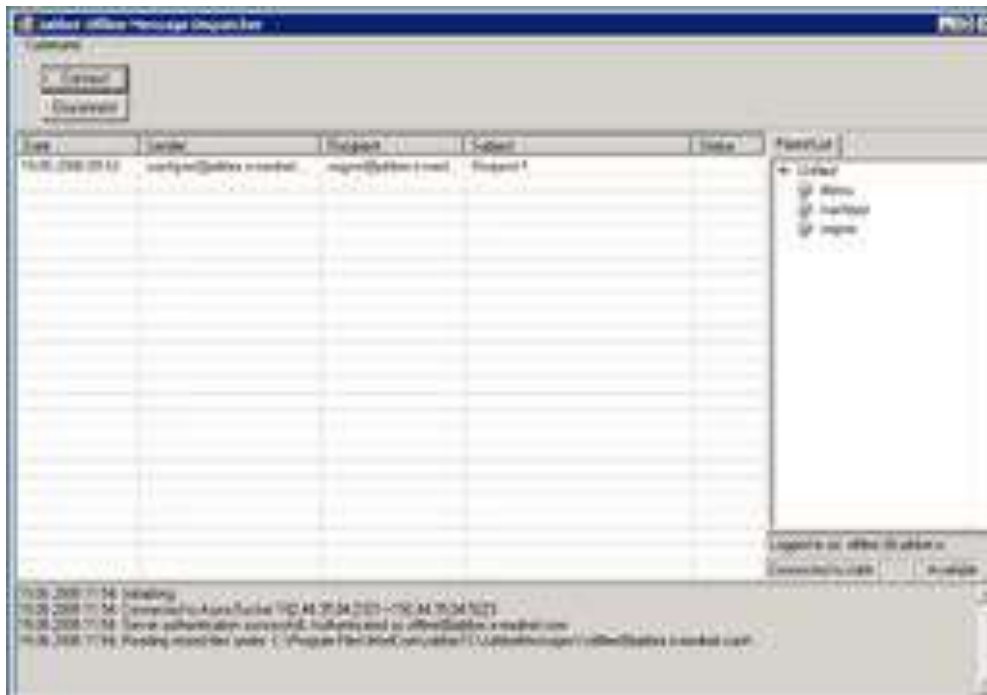


Figure 3.12: Offline message dispatcher

sensitive. The transmission rate would also be slower than real-time or even the data can be transmitted in bulk any at specific time during the day or night.

In particularly, throughout an off-line communication the following events are taking place:

- The patient is examined in a normal hospital. Images are acquired for the patient
- The doctors decide to contact an expert center. Therefore an off-line message together with the images of the patient is compiled
- The message is sent to the expert center
- In the expert center, an expert reads the message and investigates its content
- The expert creates comments to the images and answers the message together with its comments

During an off-line communication the medical imaging data are sent to a messaging dispatcher application. The reason of the development of this messaging dispatcher application is to not overload the jabber server with the messaging storage, since off line medical messages would be very large files e.g. 500 MB or more.

In Figure 3.13 are depicted the involved parts of an off line communication.

Physician-A is preparing an ultrasound off-line message for physician-B. The off-line message, independently of physician-B's presence status, is sent to off line messaging dispatcher, where all off line messaging are stored. As soon as the message is stored on the dispatcher, the physician-B will receive a notification message for downloading a new message from the dispatcher.

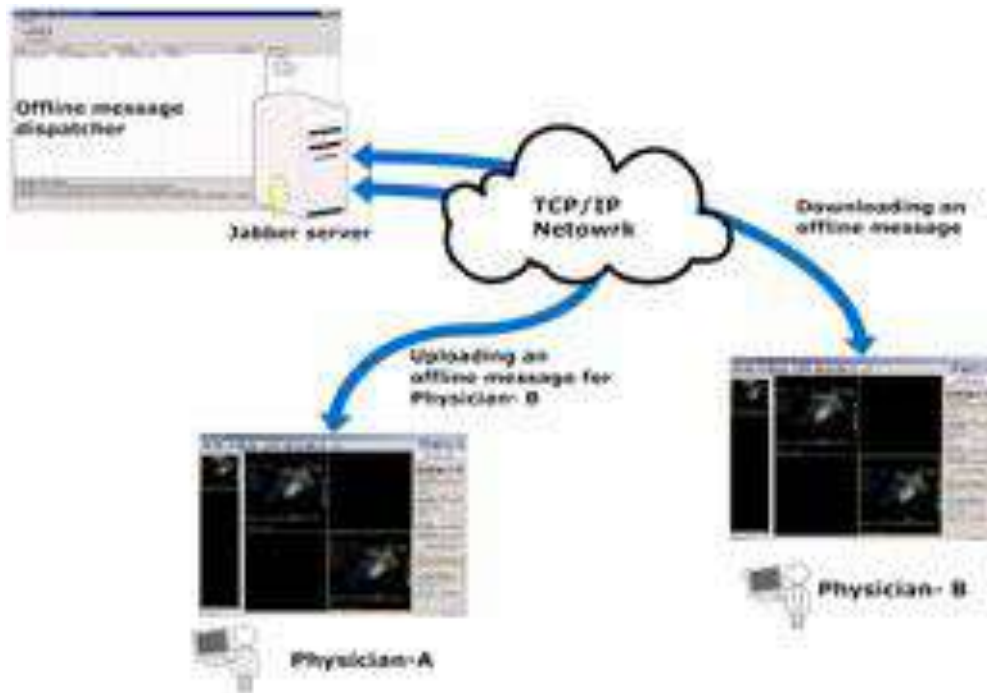


Figure 3.13: Offline messaging transfer flow

In terms of communication protocols adaptation and specification the off line messaging procedure makes use of the in-band-data protocol a long with the protocol extension as proposed in section 3.3 for both uploading and downloading a message to message dispatcher.

3.6 Security issues

Jabber supports SSL (secure sockets layer) encryption, a common encryption method used on the Web. SSL uses a cryptographic system that uses two keys to encrypt data - a public key known to everyone and a private or secret key known only to the recipient of the message.

Jabber encrypts the connection between the Jabber client and the server and instant messaging communication remains confidential in that way.

3.7 Results, innovation and own contribution

In chapter 3, I depicted extensions of jabber protocols for supporting off-line imaging medical data and on-line communication among users/doctors.

In particular, making use of XML messages, the the initial data amount increases of 33.33% due to base64 encoding of the binary data. In this way the transmission time has been increased 33.33% over the same communication channel comparing also to a binary protocol transmission.

In addition, for the on-line collaboration mode, the adequate bandwidth for exchange events among the end user is larger and the narrowest one need to be ca. 5 KB/s, for a intuitive and real-time interaction among end users. In addition, I introduced grouping of applications events achieving narrowing of the communication effort over jabber protocol.

Throughout my implementation and application of the current protocol modifications, I strongly supported:

- mobilization of the doctors
- presence status of the doctors and end users
- any-time and any-place connectivity overcoming limitations due to firewall protected networks
- real-time synchronization of two or more end users, sharing the same graphical interface
- off-line data communication and exchange

Concluding, I have to highlight that Instant Messaging has advantages with direct impact on the communication schema and interactivity among end users.

Instant messaging offers real-time communication and allows easy collaboration, which might be considered more akin to conversation. In contrast to e-mail, the parties know whether the peer is available. IM allows the user to set an online status or away message so peers are notified when the user is available, busy, or away from the computer. On the other hand, people are not forced to reply immediately to incoming messages. For this reason, some people consider communication via instant messaging to be less intrusive than communication via phone.

However, some systems allow the sending of messages to people not currently logged on (offline messages), thus removing much of the difference between IM and email. Furthermore, applying my protocols extension, Jabber IM supports off-line file transaction.

Off-line messages sent by our Medical Imaging collaboration application are temporarily stored on the Jabber server. This means that two users can exchange messages independently, even if the two workstations involved are not connected to the network at the same time, as it is prerequisite for a point-to-point connection. I need to underscore that users with very fast connections to the Jabber server are able to transmit data very fast and independently of the available bandwidth of the receiving user.

In a point-to-point connection the transmission speed of two users, located in different networks, is always equal to the lowest transmission rate of two networks. For instance, if the doctor A is connected to the Internet over an ADSL connection the link's speed could be 100 Kbytes/sec. Another, doctor B using universities network could have a connection up to 1000 Kbytes/sec. If we assume that the Jabber server is located on the network with speed connection more than 1 Mbytes/sec, and the doctor-A would like to convey large volume of medical images e.g. 500 Mbytes, the doctors-A needs about 8.3 min to transmit the data. The doctor-B needs about 1.4 hours, since he is connected to a slower network.

Instant messaging allows instantaneous communication between a number of parties simultaneously, by transmitting information quickly and efficiently, featuring immediate receipt of acknowledgment or reply. In certain cases IM involves additional features, which make it even more popular, i.e. to see the other party, e.g. by using web-cams, or to talk directly for free over the Internet.

It is possible to save a conversation for later reference. Instant messages are typically logged in a local message history which closes the gap to the persistent nature of e-mails and facilitates quick exchange of information like URLs or document snippets (which can be unwieldy when communicated via telephone).

Taking advantage of the offered features and the protocol extensions developed, I adapted IM technology to a medical environment for both real-time and store-and-forward communication among doctors.

Chapter 4

Integration of telemedicine devices

4.1 Traumastation

Introduction

Covering the mobility of the medical doctors as well as integrating the diversity of telemedicine devices, I developed a portable medical device called *Traumastation*.

The medical traumastation is an ultra-light portable tele-medical first-aid device, which provides the physicians with an ultrasound, electrocardiogram, blood pressure, oxygen meter apparatus all in a suitcase, as shown in Figure 4.1. In addition, the ultra portable device is equipped with all available telecommunication gateways (e.g. GSM, UMTS, ISDN, DSL, Satellite) providing a great communication convenience to the physicians.

System description

Medical equipments and cabling

In one small box I assembled and cabled the medical sensors to a portable computer board. The whole system is capable of operating with batteries and also capable of being connected to power sockets that deliver 110/220 Volts (Figure 4.2).

The Traumastation integrates the following medical devices:

1. OEM 12-Kanal-ECG-Module is a miniaturized module providing 12 leads ECG (Figure 4.3). The device has an open communication protocol and can very easily be integrated into patient monitoring devices. For the communication, the EKG12-UART/RS232 utilizes the standard UART port and also an RS232 port. In addition, the device can be powered via the UART port and no additional source power is needed. The power consumption is less than 140 mA and a voltage of 5V is needed. Sampling rate per channel is: 100 Hz, 500 Hz and 1000Hz. The resolutions is 19bits.



Figure 4.1: Traumastation prototype

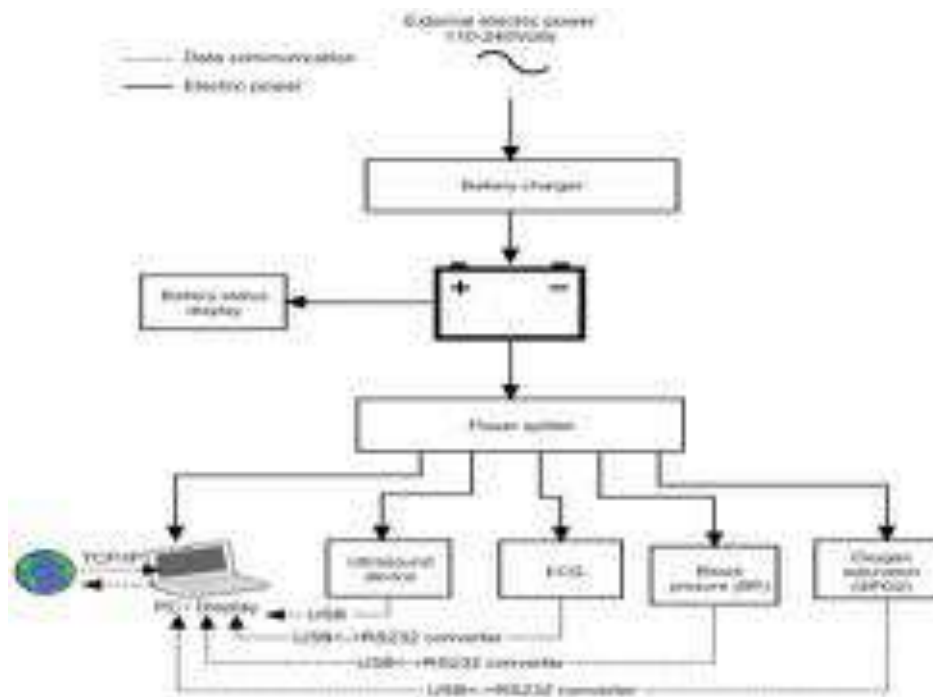


Figure 4.2: Medical Traumastation (MTS)



Figure 4.3: ECG OEM module

2. iPod module is a miniaturized module providing information on patient's blood oxygen level and pulses (Figure 4.4). The device is able to be connected over RS232 and external power is needed for the operation. The sampling rate is 1 Hz with resolutions of 24 bits.

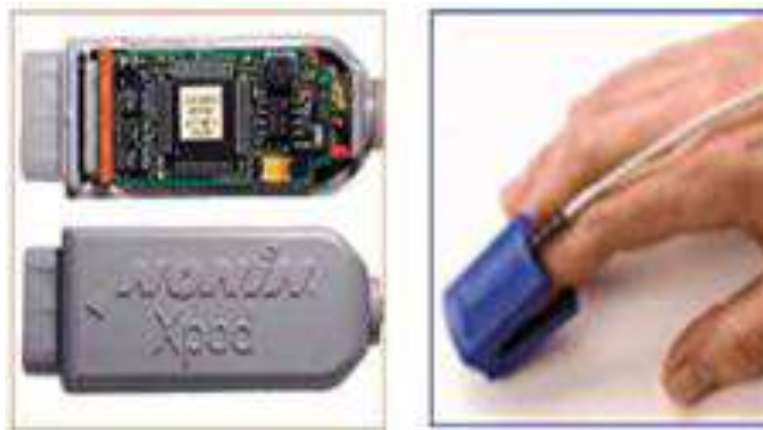


Figure 4.4: iPod OEM module

3. Advantage OEM BP Model 2 is a blood pressure module that uses oscillometric method of blood pressure measurement, a non-invasive method that monitors the amplitude of cuff pressure changes during cuff deflation to determine arterial blood pressure (Figure 4.5). The module is controlled via software commands issued from a host system through an asynchronous serial data port (factory configurable to Logic Level or RS-232). Serial communications baud rate is 9600, with 1 start bit, 8-bit data, no parity, and 1 stop bit. There is no hardware or software flow control. The sampling rate is 1 sample per 30 min with resolution of 24 bits.
4. Echo Blaster 128 is an ultrasound scanner. The beamformer can be connected to an PC via USB port. The ultrasound scanner works with 256 colours in gray scale. In addition it supports full-motion and full-size real-time ultrasound imaging, up to 120 fps as well as cineloop recording/play (several thousands frames depending on computer memory size and scan mode)



Figure 4.5: Advantage OEM BP Model 2



Figure 4.6: Echo Blaster 128 ultrasound scanner

Data representation and handling

For the the imaging data representation and handling Traumastation uses the jabber-enabled version of TeleConsult, as has been described in section 5.4. In Figure 4.7 the ultrasound acquisition application is illustrated.

For both the presentation and the acquisition of the biosignals I developed a new application called *VITAL*, as illustrated in Figure 4.8

The physician is able to create new patients and add new studies for each patient (Figure 4.9). In addition, the physician making use of the acquisition module is capable concurrently to acquire ECG waves (12 leads) (Figure 4.10), blood pressure and oxygen saturation. The recorded signals are stored into the local data repository. Particularly, ECG data is stored in SCP-ECG standard.



Figure 4.7: Ultrasound scanner acquisition mode



Figure 4.8: Vital viewer for ECG, SPO2, BP and medical annotations

Patient ID	First Name	Last Name	Age	Entry Date
11	Mark	Curry	28	11/01/2008 11:30:00 AM
14	Nancy	Purkayast	28	05/01/2008 11:30:00 AM
16	Mahesh	Vaidan	45	05/01/2008 11:30:00 AM
18	Chandler	Thomson	24	05/01/2008 11:30:00 AM
17	James	Lee	35	10/01/2008 4:04:00 PM
19	Fernando	Muller	40	04/01/2008 12:00:00 PM
13	Fernando	Muller	40	04/01/2008 12:00:00 PM
20	Mark	Lee	28	04/01/2008 12:01:11 PM

Study ID	Patient ID	Starting Time	Comments
12	17	11/01/2008 4:02:02 PM	
15	17	11/01/2008 4:02:02 PM	
14	17	11/01/2008 4:02:02 PM	
18	17	11/01/2008 4:02:02 PM	
16	17	11/01/2008 4:02:02 PM	
17	17	11/01/2008 4:02:02 PM	
19	17	11/01/2008 4:02:02 PM	
20	17	11/01/2008 4:02:02 PM	

Figure 4.9: Patient database

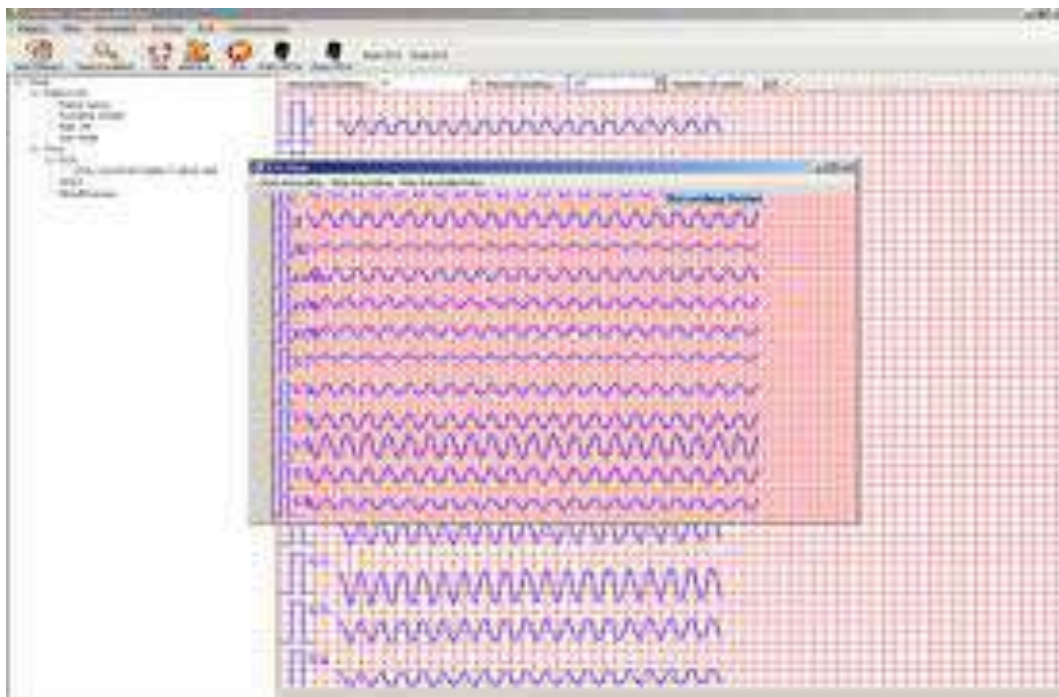


Figure 4.10: Acquisition of vital waves

SCP-ECG protocol

Traumastation makes use of two medical standards for storing and transmitting medical information:

- DICOM
- SCP-ECG

The implementation of the Standard Communication Protocol for Computer-assisted Electrocardiography based on the current version prEN 1064:2002 prepared by CEN/TC 251.

Standard Communication Protocol for Electrocardiography is supported by the European Committee for Standardization (CEN) in the field of Health Information and Communications Technology (ICT) (CEN/TC 251).

The European standard EN 1064:2002 is the document that explains SCP-ECG. It was written by CEN/TC 251 WG IV under a mandate M/255 given to CEN by the European Commission and the European Free Trade Association. It is a revision of the European prestandard ENV 1064:1993.

SCP-ECG specifies the content and structure of the information, which is going to be interchanged between digital ECG carts and computer ECG management systems. This standard is related to the conventional recording of the electrocardiogram, the so-called 12-lead electrocardiogram.

A global overview of SCP-ECG data structure is given in Figure 4.11

A specific and most attractive feature of an SCP record is the built-in self-identification mechanism: as the pointer section already gives an overview of what is within the whole record contained mostly already from the header of each section it can be determined which of the possible options for the information content of that section have been chosen. Therefore, a format and content checker *pre-processing* the SCP record can derive all necessary information to control a specific viewer or, respectively, select a viewer for the desired application profile (e.g. display of the ECG waveforms with or without beat annotation, processing results like global measurements, interpretation or over-reading results up to detailed lead measurements).

The SCP standard specifies that the information described globally above has to be structured in sections as shown in the table below.

Each section is divided into two parts:

- The section ID Header
- The section Data Part

While the section ID header always has a length of 16 bytes, the section data part is variable. Note that the complete section length (relevant for the section length information) includes the length of the ID Header (Figure 4.12). The SCP standard allows for a rather large number of options to store and format the ECG data. ECG data may be acquired at different sampling rates, with different quantization levels, they may be not compressed

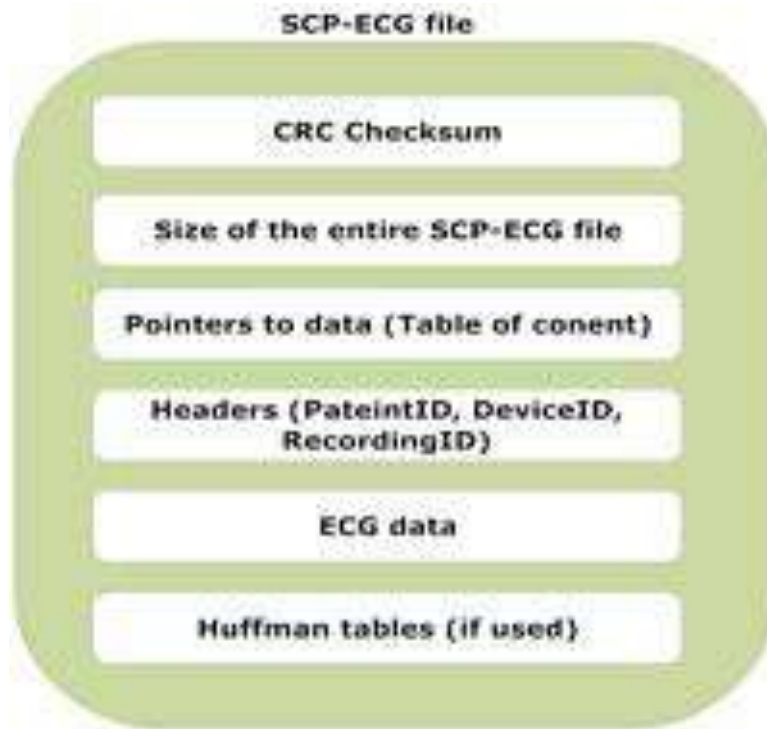


Figure 4.11: SCP-ECG data structure

Records	Size (Bytes)	Mandatory	Optional
CHECKSUM-CRC over the entire record	2	x	
Size of the entire ECG record in bytes	4	x	
(Section 0) - Pointers to the data		x	
(Section 1) - Header information - Patient data/ ECG acquisition data		x	
(Section 2) - Huffman tables used for encoding of ECG data			x
(Section 3) - ECG lead definition			x
(Section 4) - QRS locations			x
(Section 5) - Encoded reference beat data			x
(Section 6) - Residual signal			x
(Section 7) - Global measurements			x
(Section 8) - Textual diagnosis from the interpretive device			x
(Section 9) - Manufacture specific diagnostic and interpretation			x
(Section 10) - Lead measurement results			x
(Section 11) - Universal statement codes resulting from the interpretation			x

Table 4.1: Detailed SCP-ECG structure

or be compressed by selectable methods and an SCP-ECG record may or may not contain analysis and overreading results. Also, the number of leads, the length of the recording interval and even the simultaneity of leads is left open to the manufacturers.

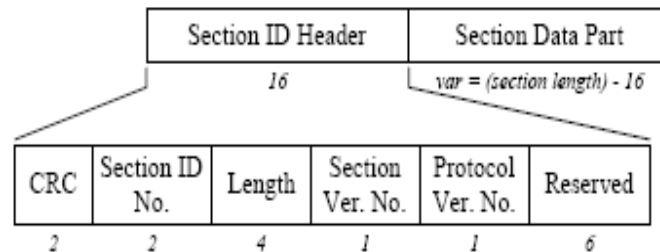


Figure 4.12: SCP-ECG section structure

Data repository

The repository stores all pieces of information that are being used in the context of the application. Because of the fact that the application uses various types of information, the repository consists of various databases, which could be combined in the same physical DB or be distributed if needed.

Specifically, information used in the application is categorized as follows (Figure 4.13):

- Medical Data Repository (MDR)- This is a database, which stores all patient's vital data, as transmitted from the medical devices
- Patient Profile Database (PPD) - This is the database storing all information about the registered patients
- Medical Staff Database (MSD) - This database holds information about doctors and paramedics

Data exchange methods

Traumastation provides two type of collaboration: on-line collaboration and off-line messaging. The messaging is utilized with the help of jabber protocol. The application makes uses of the jabber communicator to send and receive messages from other users (Figure 4.14)

The on-line collaboration needs the two physicians to be on-line at the same time, whereby off-line messaging does not require that the remote communication partner is available, when the messages are sent.

Both methods have its advantages and disadvantages. On-line sessions have more options for the interaction and exchange of information. Especially within TeleConsult the principle

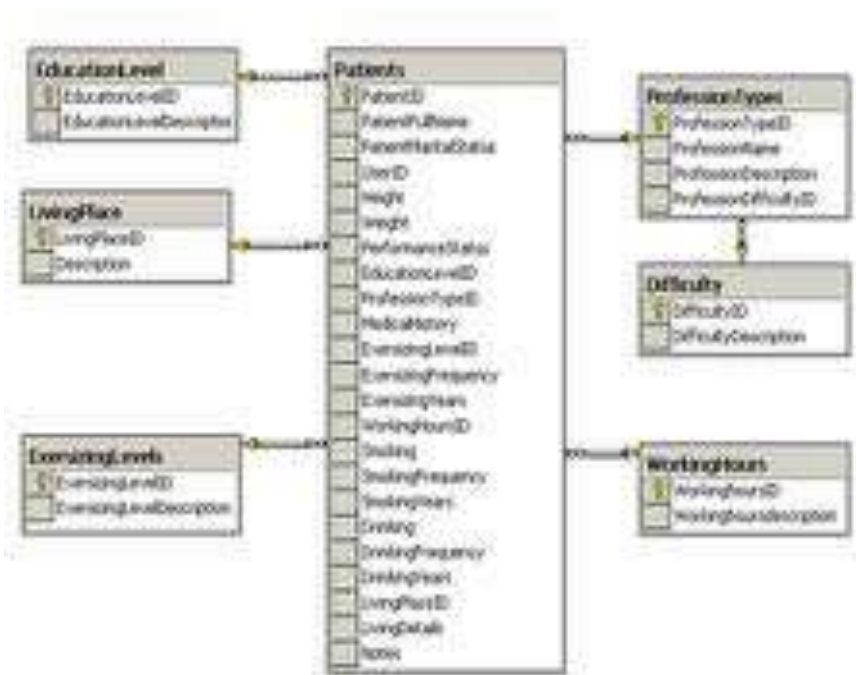


Figure 4.13: Patient database schema

what you see is what I see (WYSISIS), which means that both partners are having the same view at the images during the online-session, has great advantages (Figure ??). The main disadvantage is that both communication partners need to be available at the same time, which is on the other hand the main advantage of the offline-method.

Bandwidth requirements

The range and complexity of telecommunication technology vary with the specific medical application. Transmission of medical images would require more bandwidth. However, tele-consultations of ultrasound images requires only a few megabytes of data. On the other side, transmission of biosignals might also need adequate bandwidth. The bandwidth needed for biosignals and ultrasound images is depicted in Table 4.2.

Signals measurements	Bandwidth
ECG 1 lead	3,6 KB/s
ECG 12 leads	43,2 KB/s
Pulse oxymeter (SpO ₂)	72 B/s
Heart pulse	24 B/s
Blood pressure	32 B/s
Ultrasound imaging	256 Kb/s
Video conference	25 Kb/s

Table 4.2: Bandwidth needed for real-time transmission



Figure 4.14: Jabber communicator is used to exchange information among physicians



Figure 4.15: Two physicians are sharing the same view during an on-line session

4.2 Medication adherence

Giving the definition of medication adherence, we can define adherence as *the extent to which the patient follows medical instructions (i.e. taking medication, following a diet)*. Mainly we refer to medication adherence, which means to which extent a patient follows medication prescriptions.

The major method of treating disease in the developed world is through the prescription of drugs. It is estimated that, on a global basis, three billion prescriptions are issued annually. The cost of prescription drugs to Europe amounts to 15% of the annual GDP [85, 86, 87]. The vast majority of these prescriptions are used effectively and result in the cure of the illness. The surprising fact is, however, that a significant amount of prescriptions are wasted simply because drugs are not taken as prescribed by the general practitioner (GP).

According to estimates, up to 66% of patients, particularly those suffering from mental disorders, fail to adhere [88, 89] completely to their prescription by taking only some of their medication or in many cases none at all [90]. This failure to comply with a medication regimen is referred to as non-adherence.

In this chapter, I am describing an algorithm for assessment of medication adherence based on image processing and analysis. This algorithm reconstructs black/white images from the data of the timestamps a patient accesses a medication dispenser. The black/white images are used as input for the entropy of the system. Then the index of the entropy is used to describe patient's medication adherence.

Introduction

Taking as example the mental illness it comprises a large number of disorders of abnormal mood thought and behaviour. At any one time one adult in six suffers from mental health problems of varying severity. These include a wide spectrum of conditions, from anxiety to psychotic disorders such as schizophrenia. In most cases mental disorders run a chronic, recurrent course resulting in disruptions in education and employment, family and marital problems and social marginalisation.

The World Health Organization's (WHO) World Health Report 2001 showed that in 1990, mental illness and neurological disease accounted for approximately 10% of all DALY's (Disability Adjusted Life Years). This number grew to 12% by 2000, and is expected to rise to 15% by 2020.

The prevalence of narrowly defined syndromes for schizophrenia and manic depression is about 1% and of depressive disorders about 9% at any given time. Although non-adherence to medication is common amongst all patient groups it represents a specific challenge for patients with mental illness. The rates of non-adherence within out-patient settings has been found to range from 40-70% approximately. Non-adherence increases the risk of relapse by a factor of 5 and poor adherence contributes to poor symptom control [91].

Both these factors have significant social and financial consequences:

1. Poor medication adherence poses a heavy burden on patients. Because of the frequent and prolonged relapses or poorly controlled symptoms patients are unable to

maintain paid employment, achieve educational goals or sustain meaningful social relationships. Relapse is also associated with frequent and prolonged hospitalization and heavy use of assertive, crisis and emergency services. In addition, poor symptom control contributes to the risk of violence by patients.

2. Poor medication adherence leads to marginalisation and stigmatization of patients. Because of the negative consequences of poor adherence outlined above, this issue is one of the most significant contributors to the social exclusion of mentally ill patients.
3. Poor medication adherence is an important problem for family and carers. Because of the increased disability, dependence and need for care, poor medication adherence is associated with significant mental problems in carers as well as financial difficulties as they need to take time off work to look after their ill family member.
4. Poor medication adherence contributes to the high cost of mental illness. Frequent hospitalizations and heavy use of services comprise the main bulk of direct costs for caring for the mentally ill.

Methods

Some of the methods for estimating medication adherence [92, 93] already applied in the past, unfortunately without so much success, were:

- Patient's self report. The patient reports to the physician or nurse his medication compliant and if there were any deviations for the medication treatment. This method has shown very low medication adherence [94]. Patients often lie when they requested about their medication compliance.
- Pill-counting. During regular visits, the physician or nurse counts the number of the returned pills and calculates the ratio of tablets returned over those that should have been taken. However, pill-counting inaccuracies are common and typically result in overestimation of adherence behaviour [95].
- Blood tests over regular visits. This method represents the medication adherence for a few preceding weeks [96].

The most recent method applied to patient with mental disorders was the monitor of medication adherence with the help of electronic means. This method delivers much better results than the methods above as depicted by [97, 98]. Furthermore, this method has been proved to be more accurate and reliable. Diaz et al [98] conducted a small study with 14 patients, making use of electronic monitoring in schizophrenia. The study ran over a period of 6 months and the mean adherence rates were 63% for the first month and varied from 56% to 45% over the next five months.

A few researchers [97, 98] used monitoring systems that did not involve tele-monitoring of patients. The recorded data were downloaded from the electronic medication dispenser when the patient visited the doctor at the clinic. The importance, however, to monitor the patient from distance in daily fashion provides physicians with meaningful information on patient's medication adherence. Physicians in case of non-adherence are able to intervene and encourage the patients to continue adherence and prevent discontinuation.

System architecture

In this section I depict the overall system architecture and how the various components are being connected to each other. The main components of the system can be seen in Figure 4.16 and are described in the successive sections, in greater detail.

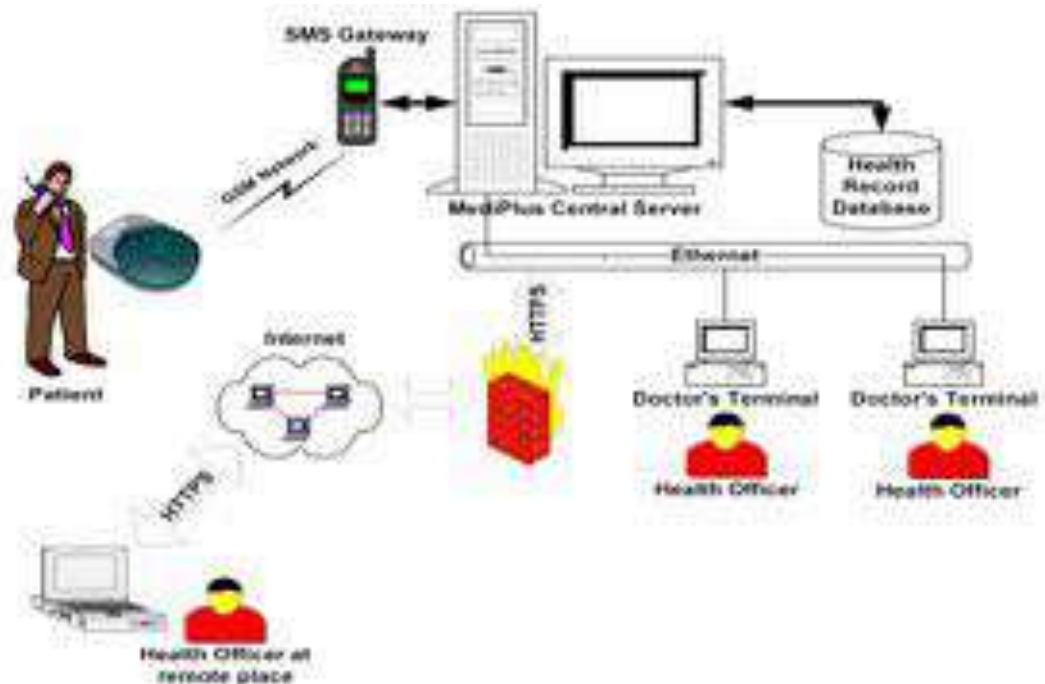


Figure 4.16: Medication adherence overall system architecture

Data acquisition

A medication dispenser or pill dispenser, developed by AARDEX Ltd [99], as shown in Figure 4.17 is a device which alerts and monitors intake of medication.

Based on the events extracted from the medication dispenser device, I developed an algorithm for predicting the medication adherence trend of patients.

In Figure 4.18, I depict the medication events recorded by the medication dispenser. In more details, green spots mean that medication taken in time, blue spots represent slight deviation from the predefined time, and red spots represents missing medications.

In the following section I am going to describe a methodology of assessing the patients' medication adherence based on the imaging entropy and correlating random patient behavior to imaging information.

The process of estimating patient behavior based on entropy index follows four (4) basic steps, as illustrated in Figure 4.19.



Figure 4.17: Electronic monitoring of compliance by AARDEX

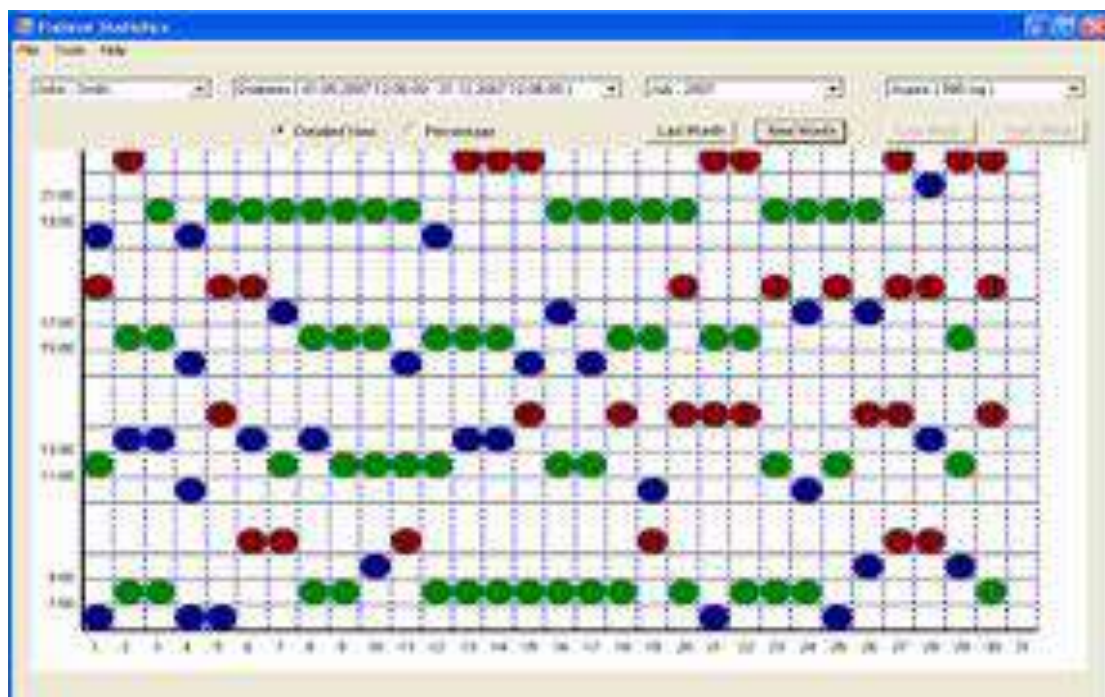


Figure 4.18: Presentations of adherence events

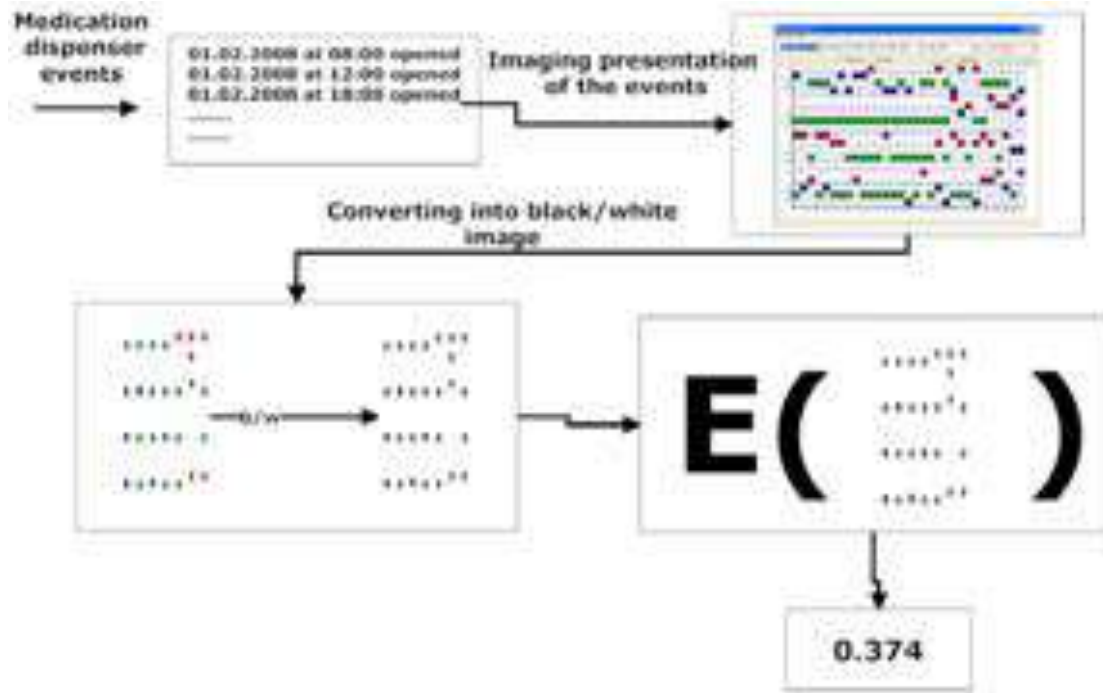


Figure 4.19: Estimating entropy index from medication events

Entropy analysis

Entropy is the most influential concept arising from statistical mechanics. It was originally understood as a thermodynamic property of heat engines that inexorably increases with time. Entropy has become science's fundamental measure of disorder and information, quantifying everything from compressing pictures on the Internet to the heat death of the Universe.

Liquids have higher entropy than crystals intuitively because their atomic positions are less orderly [100, 101]. There are interesting examples of systems that appear to develop more order as their entropy (and temperature) rises [102, 103]. These are systems where adding order of one, visible type (say, crystalline or orientational order) allows increased disorder of another type (say, vibrational disorder). Entropy is a precise measure of disorder.

The entropy [104] $H(x)$ of the data x is defined by (4.1):

$$H(x) = - \sum_{k=1}^n p(k) \log_2(p(k)) \quad (4.1)$$

where p_k , $k = 0$ to $n-1$, is the probability of the k^{th} quantiser level being used and obtained from a histogram of the pixel intensities).

In computing entropy we have followed the steps:

1. Form a histogram of the input. $histo = hist(V, min(V) : max(V))$;
2. Estimate the probabilities (P_i). $probabilities = histo/sum(histo)$;

3. Calculate $\log_2(P_i)$. $\log_2(P_i) = -\log_2(\text{probabilities})$
4. Calculate inner product. $P_i * \log_2(P_i) = \text{probabilities} * \log_2 P_i$
5. Finally sum up. $H = \sum P_i * \log_2 * P_i$

I developed an assessment method using medication events. From the monthly presentation of dispenser events, I produce 2D images representing weekly medication events, as shown in the figures 4.20 and 4.21 below, calculating the entropy.

4.3 Results, innovation and own contribution

As it has been indicated previously entropy is a precise measure of disorder. Based on that, we can infer the patient's medication compliance analysing the entropy of the 2D images produced from the medication events recorded by electronic medication dispensers.

Therefore, when randomness of the pixels of the image is high -disorder-, it means the information content (entropy) is high. In other words, the information content of the reconstructed images obtained from the data of each week can directly be linked to patients' behaviour and their medication compliance.

In Figure 4.22, I depicted the entropy of the weekly medication events in conjunction with the time. As for the data of the patient in 12th to 16th week, by which time he had low medication compliance, it seems to be distributed, unlike any other data of the previous weeks. The entropy of the images is increasing from the 12th week. As rule, we have concluded that as the entropy of the image increases, the non-adherence to the medications of the patient increases, as well, since the events follow no order. Actually, no order for system can directly be interpreted to sporadic intake of medication and deviation of the medication prescription.

In Figure 4.23 I have normalized the entropy values. The point at (1,1) represents a *perfect* week without any deviation of the medication prescription. Values greater than 1 indicate deviation of the treatment planing.

In this way the system is able to alert carer of patients who tend to be non-adherent. The evaluation of the entropy index provides information of the adherence tendency of the patient and the physicians or nurses are capable to alert in time the patient avoiding major deviations of the prescription planing.

According to World Health Organization adherence to long-term therapy for chronic illness in developed countries averages 50%. In developing countries, the rates are even lower. It is undeniable that many patients experience difficulty in following treatment recommendations.

Several support systems of the daily life in chronically ill patients (i.e. the elderly, cardiac patient, diabetes, mental ill patient), using the information network, have been proposed [105, 106, 107, 108, 109]. We had also proposed and operated, experimentally, the home healthcare system [19, 110, 18], which is a combined system of the information network and biomedical sensor system. Systems such as the one we proposed acquire biomedical data and medication dispenser events from the patient from which their medication adherence can be assessed.

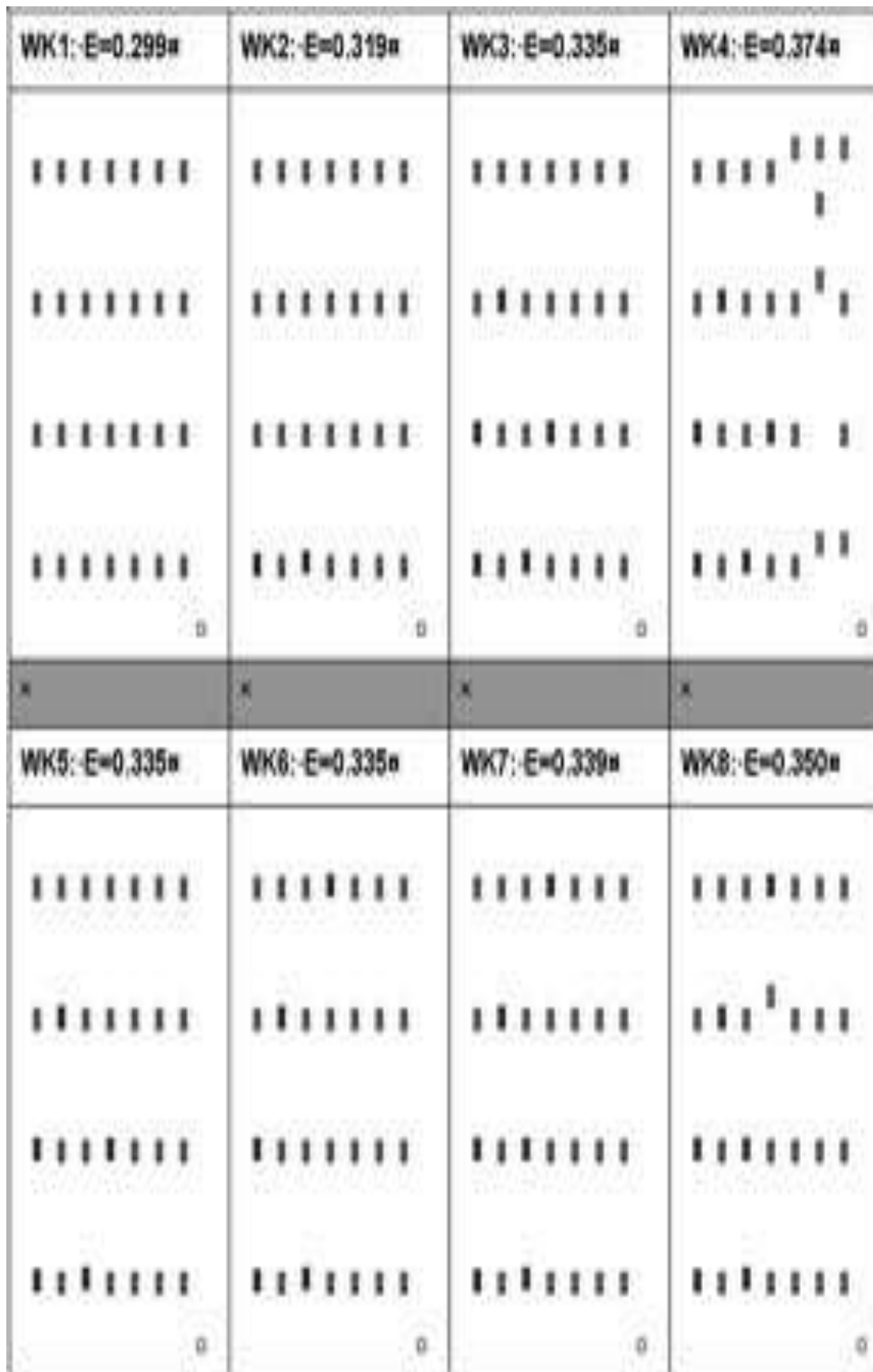


Figure 4.20: Entropy from week 1 to week 8

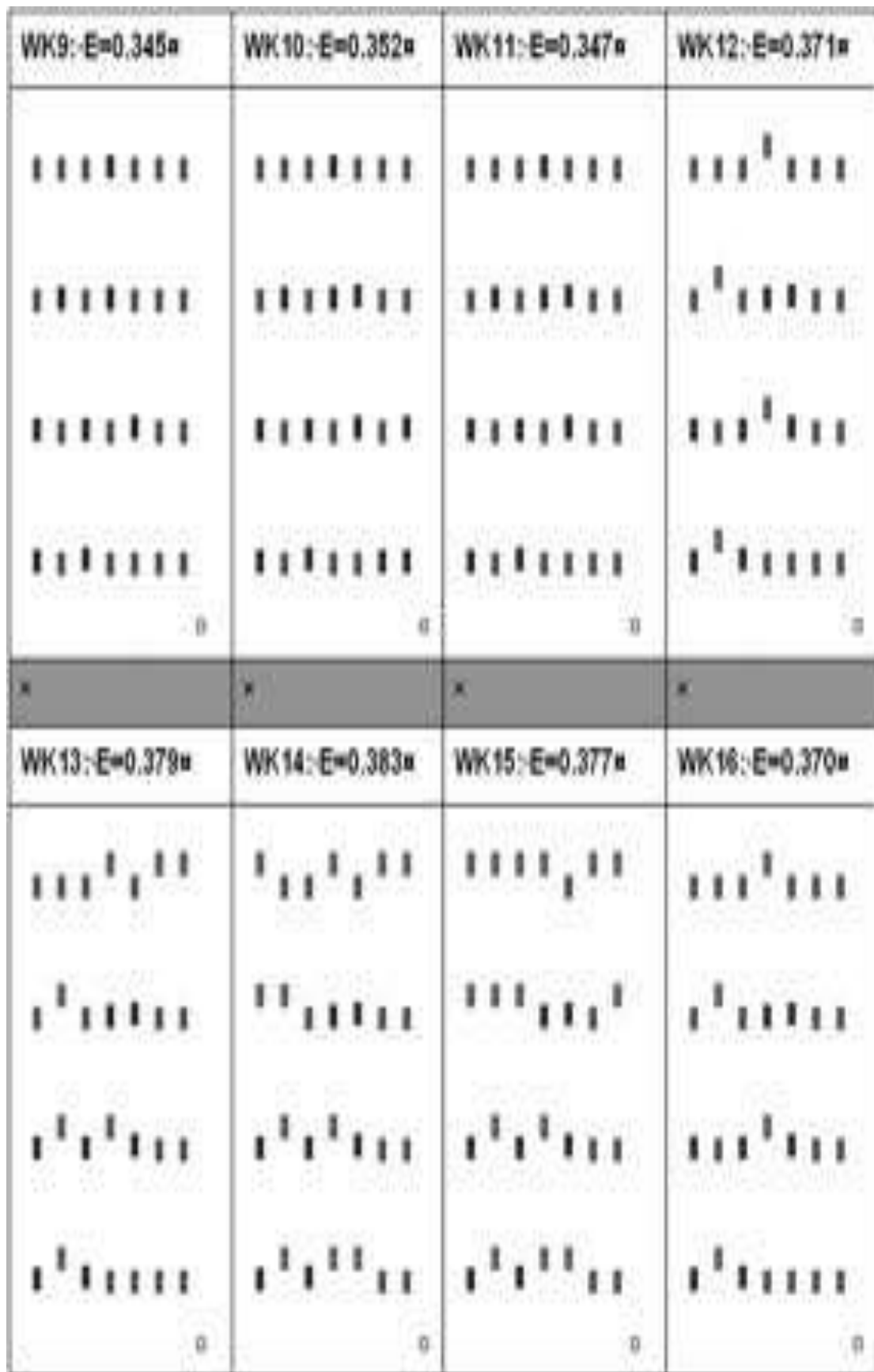


Figure 4.21: Entropy from week 8 to week 16

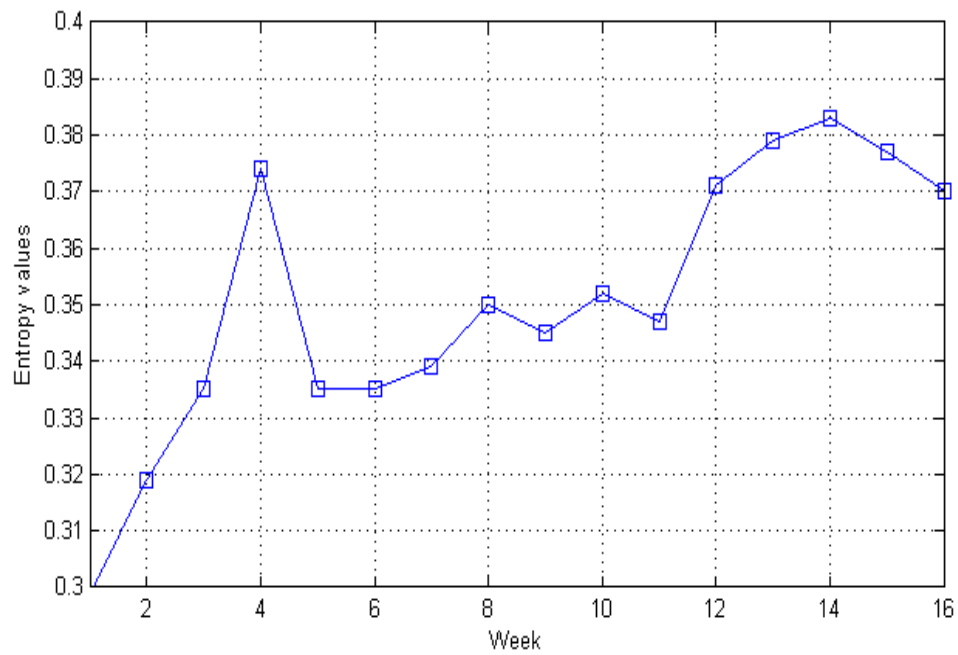
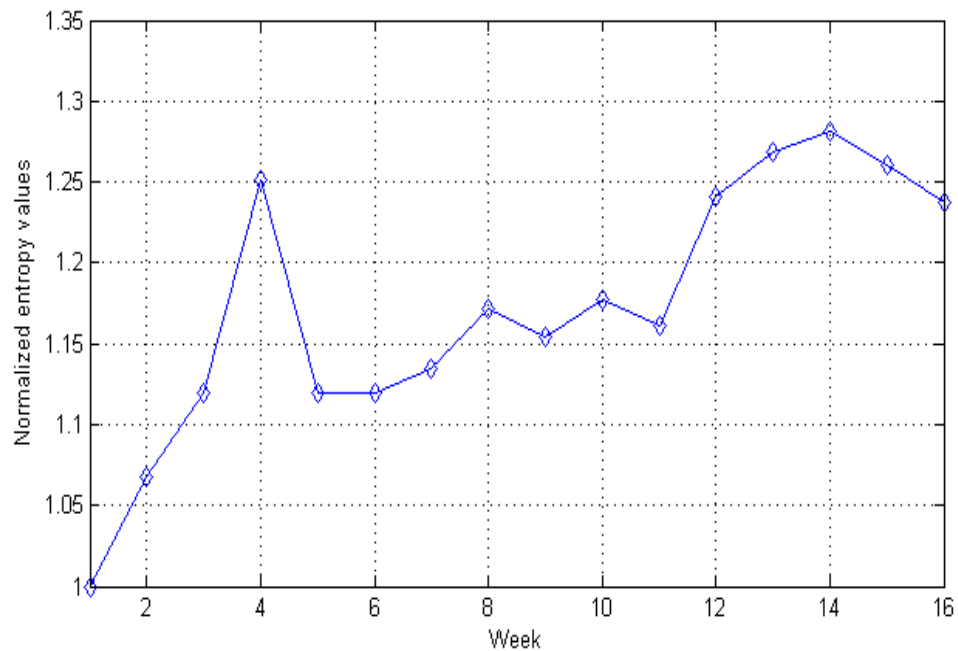


Figure 4.22: Entropy variation through weeks

Figure 4.23: Normalization of the entropy values to a *perfect* week

Furthermore, a multi-functional, portable telemedicine kit (Traumastation) was designed and constructed primarily for use in the developing world integrating various telemedicine devices. The kit is low-cost compared to the alternatives that exist today and offers much of the same basic functionality.

The kit was designed to the specifications determined by studies of the most common medical diagnostic needs of patients in rural communities for radiology, emergency and home-care applications.

Chapter 5

Applications

In this section I will introduce the projects where the aforementioned work was applied in practice. Four projects have taken advantage of the developed system. The projects were: **@HOME**, **T@LEMED**, **T@HIS**, **TENPET**.

	Home care	Emergency	Radiology
Applications	@HOME	T@LEMED, T@HIS	TENPET
Devices	TraumaStation (devices integration)		
Transportation Protocols	Instant messaging (just one protocol)		

Table 5.1: Applications taxonomy

In table 5.1 I categorized the telemedicine applications into home care, emergency and radiology applications. In this table I show how an instant messaging protocol and an integration of diversity of medical devices can serve various medical applications.

5.1 @HOME

Introduction

The focus of medical care in Europe and throughout the world is on community or home-based treatment across all disease areas. @HOME represents a substantial contribution to the feasibility and efficacy of home-based treatment. It addresses the needs of acute patients who demand a real-time monitoring of their primary vital signs as well as those who require long-term medication.

In the case of remote monitoring of medication adherence there are also two further potential secondary user groups:

- carer and
- pharmaceutical industry

The former appreciate the ability to contribute to their relatives' care and the latter may avail of the @HOME in the conduct of clinical trials for new medications.

@HOME project benefited fully from the balanced mix of expertise of its partners. @HOME has seven partners: two end-users (King's College London, Institute of Psychiatry, the Instituto do Coraiao Portugal), 3 technical experts (NVND, Hitech and FHG/IGD) a technology market analyst (Advanced Technologies in Business) and an industrial medical partner (EBIT Sanita). IOP-KCL and HIP led the development of two configurations of the @HOME platform in chronic and acute care respectively by defining the parameters of use and piloting the clinical evaluation. The technical experts developed the software infrastructure that comprises @HOME and integrated the relevant sensors. The last two partners focused and guided the dissemination efforts of the consortium and are leading the commercial exploitation plans.

Two configurations of @HOME are considered for commercial exploitation:

- The first configuration addresses the needs of patients with chronic disorders (including psychiatric disorders)
- while the second configuration addresses the needs of patients with acute cardiovascular diseases.

The major emphasis in chronic disorders is to encourage and monitor adherence to medication as the most important determinant of a good outcome. Therefore we developed a system for remote monitoring of medication adherence.

In acute cardiovascular care the emphasis is on regular and reliable measurement of vital signs. Therefore we developed a platform incorporating three stand-alone sensors, namely the SpO₂ sensor (Oxygen saturation level), the ECG sensor and the blood pressure sensor.

In both configurations, special attention was given to provide wireless and portable equipment: the patient-side system runs on a Personal Digital Assistant (PDA) and portable PC, while the chosen sensors do not exceed in size that of a PDA. The technical aspects of the @HOME were at times challenging. This is however, offset by the clear technical achievements incorporated in the @HOME platform and the completion of meaningful clinical evaluations of the platform.

This provides the @HOME consortium with a solid base for commercial exploitation. Specifically the clinical pilot in acute cardiac care demonstrated the feasibility of the @HOME approach in delivering safe home based monitoring in these patients and there are now plans to expand the clinical trial base to patients with other disorders involving cardiovascular risk, such as sleep apnoea. The clinical pilot in chronic psychiatric patients not only showed @HOME to be a practical and patient-friendly solution in monitoring adherence in this difficult group of patients, but also resulted in clear improvements in adherence.

5.1.1 Approach Followed

The @HOME consortium approached the objectives of the project along the lines of the following considerations:

- **Technical Considerations**

One of the key aims of @HOME was to develop a system that will allow for high clinical standards of care while being able to *blend in* as much as possible into the patients' normal lifestyle. Therefore the choice of hardware (sensors) and telecommunication systems was guided by this principle. Sensors were chosen to be portable and unobtrusive and telecommunication systems were chosen to suit people that can be on the move. A second consideration was that the @HOME solution should be pragmatic and feasible within the lifetime of the project. Therefore, we did not choose to develop new sensors or other hardware as the technical challenge and financial implications of this approach were both beyond the scope of the project. Instead we opted to maximise the potential of available and affordable products by integrating them into the @HOME platform. Consequently, a secondary but important consideration in choosing from existing hardware was their potential of integrating seamlessly into the @HOME platform.

- **Clinical Considerations** No medical product, service or device has any future if clinicians are not convinced that they represent value for money and they are safe. In order to address both the safety and cost-effectiveness issues we decided to pilot the application of @HOME in two challenging clinical areas:

1. mental health
2. and cardiac care

The mental health pilot focused on evaluating the potential of @HOME to promote adherence in patients with schizophrenia. Non-adherence to prescribed medication is the most widespread clinical problem in any disease area. However, schizophrenia poses an added problem in that the patients themselves often have no insight into the need for medication, which they actively try to avoid. The positive results from the psychiatric pilot are tremendously encouraging with regards to @HOME and suggest that it can be a humane and user-friendly alternative to enforced treatment in these patient populations. It also suggests that its potential in promoting adherence may be even greater in less resistive patient groups (e.g. patients with hypertension, diabetes).

The cardiac pilot focused on assessing the potential of @HOME to provide a safe alternative to hospital admission in the intensive monitoring of vital signs in cardiac patients during the recovery period following an acute cardiac event. The challenge here is that cardiac function in these patients is often unstable but the actual monitoring of their vital signs is essentially purely mechanistic. The cost-effectiveness of using expensive in-patient facilities for such simple tasks is dubious but has been the only available choice so far.

The @HOME platform achieves two things: one is to deliver a cost-effective solution by performing the mechanistic aspect of recording vital signs while offering the patients on-line expert supervision through the remote real-time link to specialist hospital units that are ready to intervene clinically if required.

- **Commercial Considerations** In deciding on the focus of the @HOME platform we considered two key issues. Firstly that the system should be able to relieve clinical

and financial pressures from within the health services from areas where such pressures are greatest. A product that can be cost effective in this way has the greatest appeal to potential clients. Therefore the focus was on a developing a platform that could impact on the highest cost component of medical care, in-patient and crisis services. *The focus on adherence aims to reduce the need for hospital admissions and to promote general well-being by encouraging patients to remain on their prescribed medication thus avoiding deterioration in their health, acute medical crisis and multiple admissions. The focus on acute care aims to reduce the length of in-patient stay for those already in hospital.*

Secondly, we targeted areas where health costs are greatest; cardiovascular disease is the most common medical problem in Europe and the western world, while mental disorders such as schizophrenia consume far more direct costs than more common disorders (e.g. asthma) because of their chronicity and disability.

Two secondary considerations that are more applicable with regards to medication monitoring is that the potential market expands beyond health care systems as other potential users are the pharmaceutical industry, currently one of the largest areas of growth in European economies, and patients' carers who may also want to help in a direct but respectful and acceptable way to the care of their unwell relatives.

5.1.2 Overview of the @HOME platform

Two configurations have been built:

- for remotely measuring medication adherence (piloted in patients with schizophrenia) and
- for remotely measuring vital signs (piloted in patients with cardiovascular disease).

Architecturally, each configuration is composed of two groups of interlinked components, the clinic sub-system and the home (patient) sub-system. The first group is located at a clinic and the other group is at the patient's home. A communication link is established between these two physically separated parts for information exchange (Figure 5.1).

Clinic Sub-system

The architecture of the clinic sub-system is composed of three layers, typical of a three-tier system. They are the following:

- **Data Layer:** this layer is composed of the data manipulated by the @HOME platform. It is composed of electronic records available in all hospitals organized and stored in databases. It is, also, composed of the @HOME database which will store other data, not available in the legacy databases.
- **Business Layer:** this layer encapsulates the business rules for manipulating the data stored in the data layer. In the @HOME system it is named Central System Server.

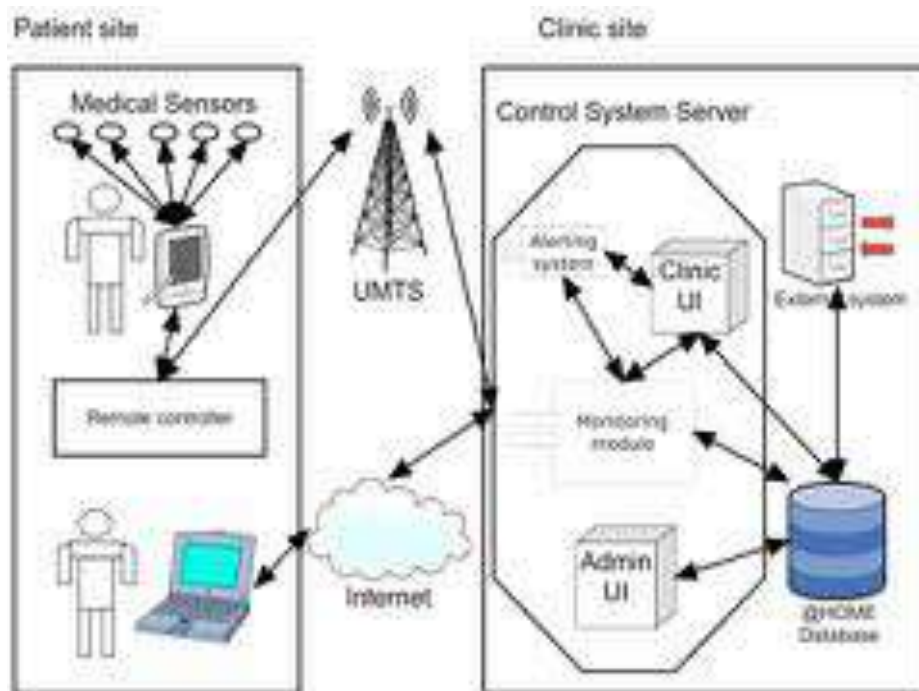


Figure 5.1: @HOME system architecture

- **Presentation Layer:** this layer is responsible for presenting the manipulated data to the users in the clinic. In the @HOME system it corresponds to the Clinic User Interface module and its function is to present information depending on the various user categories and their user interface requirements (Figure 5.2).

Home Sub-system

This part of the architecture will be physically located at a patient's home. It will implement three types of functionality: measurement, transmission and presentation. It is comprised of:

- **Medical sensors:** There will be two types of sensors: devices that will measure health parameters (this type of sensors is found exclusively in the @HOME version for patients with cardiovascular diseases) and medication dispensers (this type of sensors is found exclusively in the @HOME version for patients with schizophrenia) that will provide the patient with the prescribed medication and record whether it has been taken properly (Figure 5.3).
- **Remote Controller:** This component is transparent to the patient. That is, the patient will not use it in any sense such as changing its settings or its location. It will be fixed at some point in the patient's home. It provides the home end of the communication link between the clinic and the home. Its functionality is the following:
 1. Receive all recordings transmitted from the medical sensors and transmit them to the clinic Central System Server via a wireless infrastructure



Figure 5.2: @HOME presentation layer

SENSORS

ID	Serial Number	Type	Status	Time Table
<input type="checkbox"/>	20211123	Heart (ECG) Recorder	Available	View/Configure
<input type="checkbox"/>	120941	Medication Dispenser	Available	View/Configure
<input type="checkbox"/>	049424734	SPO2	Available	View/Configure
<input type="checkbox"/>	42942421	Blood Pressure	Available	View/Configure
<input type="checkbox"/>	120941A	Medication Dispenser	Available	View/Configure
<input type="checkbox"/>	120942	Medication Dispenser	Available	View/Configure
<input type="checkbox"/>	120941	Medication Dispenser	Available	View/Configure
<input type="checkbox"/>	120944	Medication Dispenser	Available	View/Configure
<input type="checkbox"/>	120941	Medication Dispenser	Available	View/Configure
<input type="checkbox"/>	120944	Medication Dispenser	Available	View/Configure
<input type="checkbox"/>	120947	Medication Dispenser	Available	View/Configure

Figure 5.3: View of available sensors

2. Control all the remote sensors connected to it
3. Includes the necessary software drivers for the sensors used and has an extensible architecture for new drivers

5.1.3 Data volumes and communication

The volume of the physiological signals acquired by the remote sensors played an important role for the @HOME platform. Particularly, great attention had been given to the ECG data due to large amount of data. In table 5.2 I indicate the types of acquired signals and their dependant variables.

Signals	Dependant variables
ECG	ST segment, Heart rate, QT time, ventricular beat
Noninvasive blood pressure	Systolic, diastolic, pulse rate
Pulse oxymeter (SpO2)	Oxygen saturation, pulse rate

Table 5.2: Physiological signals and their measurable variables

Each variable of the acquired biosignals has a specific length, resolution and sampling rate as summarized in Table 5.3.

Signals measurements	Sampling rate (samples/sec)	Resolution (Bytes/sample)	Information rate
ECG 1 lead	300	12	3,6 KB/s
ECG 12 leads	300	12	43,2 KB/s
Pulse oxymeter (SpO2)	3	24	72 B/s
Heart pulse	3	8	24 B/s
Blood pressure	1 per 30 min	32	32 B/s
Medication events	1 per 30 min	32	32 B/s

Table 5.3: Biosignals characteristics

5.1.4 @HOME for adherence monitoring

This @HOME configuration addresses the needs of patients with chronic illnesses that require encouragement and supervision with their medication. The pilot was performed with a most challenging group of patients in terms of medication adherence. Monitoring is achieved through the use of a medication dispenser, which collects information about the patients' medication adherence. The architecture of this @HOME version is that of Figure 5.1 where the electronic dispenser used was a Medication Event Monitoring System monitor produced by AARDEX Ltd (www.aardex.ch).

This is a medication adherence bottle that fits standard pharmacy bottles. The cap of the bottle (Smartcap) contains microelectronics that record automatically, the time and date



Figure 5.4: Medication adherence bottle - Smartcap

the bottle was opened. These data were transmitted via the standard communicator over the phone by button press after placing the bottle on the communicator and connecting the latter to a standard phone plug. The data were ultimately transmitted via GSM to the clinical team base.

At the clinical team base, clinicians were able to connect to the @HOME via the internet through a browser. Privileges to modify the content of the system were given to the study team and to the hospital pharmacists in terms of entering information regarding medication type, dose, dosing schedule and date and quantity of medication dispensed. The system was programmed to generate alerts to nominated clinicians if patients' accessed the dispensers less than 50% of the time over a one-week period (Figure 5.5).

A health professional (e.g. a pharmacist or a nurse) fills the dispenser with sufficient dosages for a specified period, which is not be less than the time interval until the next visit for refill. Once filled, the electronic dispenser functions as a stand-alone *sensor* in the sense that it records various types of events - primarily the time and date the user opens and closes the dispenser. Data gathered from these events form a patient profile of adherence to the prescribed medication. A specified health professional is designated as the person to receive alerts from the system when there are significant deviations from the prescribed pattern of pill taking. Omissions of doses are classified as alerts when they occur consistently over a period of time and not as isolated events (Figure 5.6). In addition, if a patient misses at least 50% of one week's worth of medication an alert will be sent for the immediate attention of the responsible health professional. Isolated missed-medication events do not constitute an alert but are discussed at regular appointments when the adherence profile of the patient is reviewed. The medication dispenser does not pose any restriction as to the kind of pills taken and the dosages prescribed.

The adherence database of @HOME includes the following data, as also shown in Figure 5.7:

1. A list of personal details fields
2. The current patient thresholds and alerts
3. Each patient's medication prescription
4. Medication dispensers' identification numbers



Figure 5.5: Setting sensors thresholds

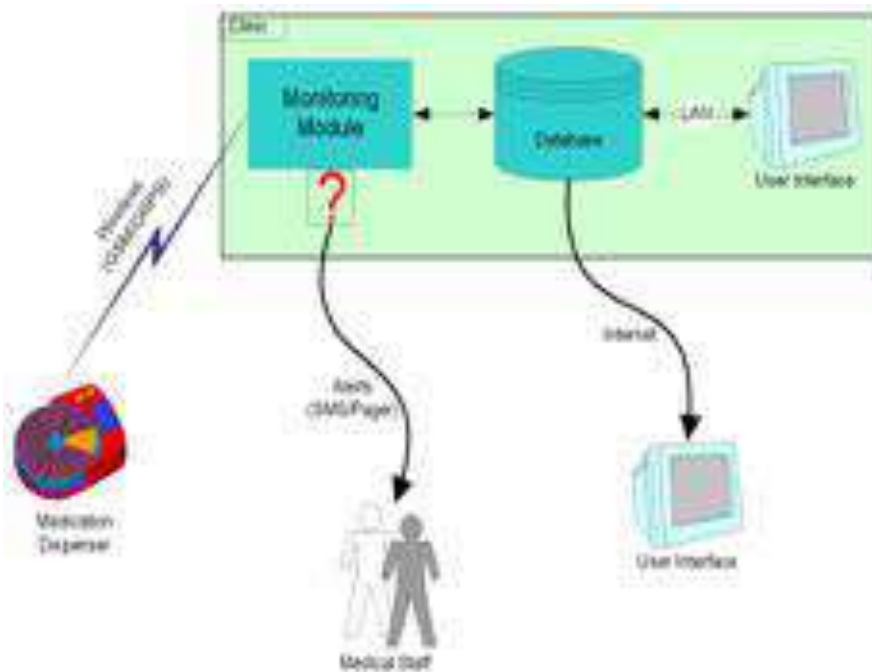


Figure 5.6: Medication adherence data flow diagram

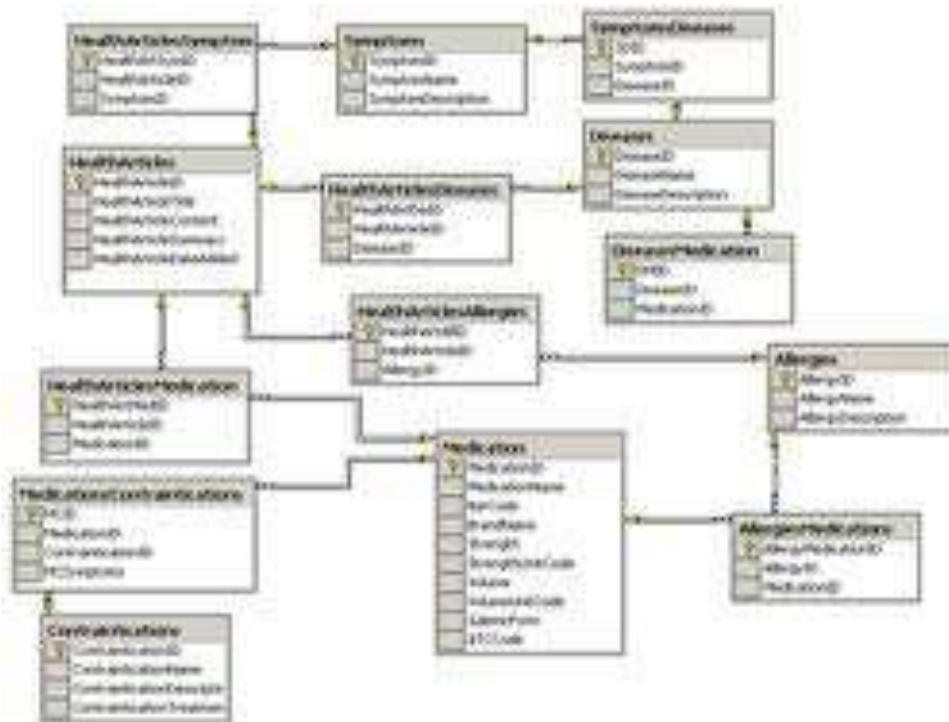


Figure 5.7: Medication database

5. Adherence events generated by the medication dispenser

5.1.5 Results from medication adherence pilot study

Background

The prevalence of schizophrenia is 1% but its financial impact on society is disproportionately large. In England alone the in-patient treatment of schizophrenia absorbs 5% of the total NHS in-patient expenditure. Although patients with chronic schizophrenia represent less than half an annual incidence cohort, their care absorbs 97% of the total lifetime direct costs. Non-adherence to medication is a major contributor to relapse and it is estimated that up to 70% of schizophrenic patients do not adhere to prescribed treatment.

Aims

This pilot application evaluated the @HOME system and studied its effect on the treatment and lifestyle of schizophrenia patients. The aim of this study was to demonstrate the usefulness of the @HOME system in reducing the crisis and relapse rate of chronically ill patients, which is directly translated to the cost of their treatment.

Design

A sample of 108 patients aged 18-64 with multi-episode schizophrenia were enrolled in the study and randomised into three equal groups. Patients have had at least two admissions in the preceding 12 months within the South London and Maudsley NHS Trust. Eligible patients were approached to obtain consent for participation. The assent of their treating physicians was also obtained. Patients were then randomised on a 1:1:1 basis to three groups:

- Group A=Self-report- Patients did not receive any intervention other than what is currently available as standard treatment within the mental health services. Compliance estimates were based entirely on information provided by patients (self-report)
- Group B=Pill counting - Adherence in this group was assessed using *pill counting* whereby the tablets used by patients are estimated by counting the numbers of tablets returned versus those administered
- Group C=E- Monitoring - Patients were provided with a medication dispenser that recorded their access and transmitted the data to the research team base. The patients' clinical team also received the same data. The clinical team was alerted if patients in this group took less than 50% of the prescribed medication over a period of a week. Alerts were followed by contact with a mental health professional (most commonly a psychiatric nurse working in the community [CPN]). In groups A and B, contact with mental health professionals was based on clinical judgment only. Information about service use was collected prospectively on a monthly basis for a period of 6 months. The cost of each component of care was based on figures from the finance department of the South London and Maudsley NHS Trust

The intervention group (group C) was given electronic medication dispensers while the control groups received either no specialist intervention or pill counting. Following randomisation into group C, patients were given a MEMSIV monitor and were asked to transmit data once a day, in the evenings. Clinicians, carers and patients were given passwords that allowed them to access the @HOME pages that were relevant to them. Patients and carers only had access to their own information while clinicians were authorised to browse throughout the @HOME site. Access to the recordings was available to all members of the clinical team looking after the patient, similarly to any other medical record held on these patients.

As this was a pilot application, the @HOME database was kept separate from the hospitals' electronic records. Patients' data were held at a server based at the Institute of Psychiatry. Apart from recordings of patients' use of their electronic dispenser, the @HOME platform generated alerts to allow the team to intervene following a period of relatively prolonged reduction in adherence. As the study aimed to assess the use of the electronic dispensers in routine clinical practice, the management plan following the alert was left entirely to the patients' clinical teams. The management of patients that clearly stated their wish to discontinue medication was also left to their clinical teams.

Information from @HOME was used in

Figure 5.8: Medication adherence: Default alerts thresholds

1. The recordings of access to the dispensers were discussed with the patient at their prearranged follow-up appointments with the view to addressing possible irregularities in dosing.
2. To generate an alert if patients accessed the dispenser for less than 50% of the time over a period of one week (Figure 5.8). A CPN made contact with the patient to discuss these lapses in dosing.

As the study aimed to assess @HOME in routine clinical practice, the management plan following the alert was based entirely on the judgment of the patients' medical teams. If a patient in any group clearly stated that they have decided to discontinue their medication, then further follow-up was based on routine clinical care alone. Staff and patients as well as carers were given tutorials on the use of @HOME and the electronic dispenser.

Clinical Assessment: All participating patients underwent a baseline assessment using the Positive and Negative Syndrome Scale (PANSS) and the Clinical Global Impression Scale (CGI) following personal interview with a member of the research team. Both scales were repeated either at study end (week 8 following randomisation) or upon study withdrawal.

Resource utilisation: These data were collected from all randomised patients and included information on hospitalisation, visits by community psychiatric nurses' (CPNs) and out-patient medical appointments. Use of services was assessed retrospectively for 8 weeks preceding randomisation and prospectively during the 8 weeks of the study duration. The medical teams responsible for the treatment of patients were required to complete on a monthly basis a one-page structured list of the number of all patients' contacts. This information was supplemented by data routinely collected on resource utilization by the hospital's IT department.

Qualitative evaluation: Patients and mental health professionals were asked to evaluate the @HOME service in terms of its acceptability, ease of use within routine clinical care and its perceived effectiveness in terms of enhancing medication adherence. Patients and professionals views were obtained through interviews using structured questionnaires.

Impact of @HOME on adherence

Patients in the control group A reported adherence rates that ranged between 10-95% at baseline with a mean of 75.3% (sd=27.6). Patients were largely consistent in their self-

reported adherence which at study end point ranged between 18-95% with a mean of 77.3 (sd= 22.1).

In the pill-counting group B, the rates of adherence were similar to those in the self-report group ranging from 50-95%, with a mean of 78.5 (sd=14).

In group C, adherence was much higher, ranging between 88-100% with a mean of 92.3 (sd=4.8). Of the 36 patients using @HOME, 5 (13.9%) opened their containers on 100% of the days, 22 (61.1%) opened the containers more than 90% of the reported days and the remaining 9 (25%) did so more than 82% of the time. Additional advantages of the MEMS system included the precise timing of container opening, which in some patients was highly consistent but in others was erratic. Irregularities seen were drug-free periods, missed doses and additional openings prior to their review by the study team.

Univariate Analysis of variance with adherence as the dependent variable and groups as factors showed a highly significant effect of group ($F=8.9$, $df=2$, $p=0.0001$). Post hoc analysis using Scheffe's tests showed no significant difference between groups A and B ($p=0.7$) while adherence in group C was significantly better than that in either group A ($p=0.001$) or B ($p=0.007$).

Impact of @HOME on clinical outcomes

At baseline, there were no group differences in the PANSS ($F=0.6$, $df=2$, $p=0.5$) and CGI total scores ($F=0.9$, $df=2$, $p=0.4$). At study end point, there were significant group differences in the PANSS total score ($F=5.7$, $df=2$, $p=0.004$). Post hoc analysis using Scheffe's tests showed that group A showed significantly less improvement than groups B ($p=0.008$) and C ($p=0.04$). No significant differences were seen between groups B and C ($p=0.8$). At study end point, there were significant group differences in CGI ($F=5.0$, $df=2$, $p=0.008$). Post hoc analysis using Scheffe's tests showed that CHI ratings were better in group C compared to both group A ($p=0.01$) and group B ($p=0.04$). Groups A and B also differed in CGI scores with group B showing more improvement (0.05).

Impact of @HOME on resource utilisation

The total number of contacts was calculated for each patient for medical, CPN and emergency visits. None of the patients had been admitted in the preceding 8 weeks and there were no admissions during the study. Multivariate analysis of variance with group as fixed factors and medical, CPN and emergency visits as dependent variables revealed no difference between the groups ($F=0.1$, $df=6$, $p=0.9$) prior to study entry. However, there were significant group differences at study end point ($F=3.6$, $df=6$, $p=0.002$). Subsequent univariate tests showed that this difference was attributed to fewer medical and emergency visits in the @HOME patient group ($p=0.01$ and $p=0.0001$ respectively).

Overview of adherence pilot study results

The benefits of @HOME were demonstrated by comparing clinical outcomes and service use between groups A, B and C. The ultimate aim in improving medication adherence

is to improve patients' mental state and reduce their dependence on psychiatric services. Patients using the @HOME showed significant improvements in the GCI compared to the two other groups. Therefore, the general clinical impression of the professionals looking after them was of significant improvement in many domains of their presentation.

Specific symptomatic improvement was also noted in this group as evidenced by the reduction in the PANSS total score. A similar improvement was also seen in group B where adherence was monitored via pill counting but was absent in the self-report group. This is in line with expected improvements in mental state following active monitoring of adherence. The @HOME system further differentiated from self-report and pill-counting methods in that it reduced the level of use of psychiatric services. The impact on CPN contacts was small but the use of @HOME led to significantly fewer medical appointments and significantly fewer emergency visits.

These results reflect to some extent the organisation of the services. CPN contacts are generally more frequent and regular with most CPN seeing patients in their caseload at least once a week as part of their case management. Therefore the number of CPN visits per patient is to a great extent fixed and expected to be around 8 visits per patient over a 8 week period. The mean contact of all groups prior to and during the study was very close to the expected average.

Patients, however, have less access to doctors who carry a significantly larger caseload. Medical appointments are often triggered in response to requests from CPNs when there are concerns about patients' mental health. Similarly, the number of emergency visits is more sensitive to patients' mental health needs and overall ability to manage their lives. Therefore, the reduction seen in the last two types of contact reflects general improvement in patients' well-being and is in line with the clinical improvement observed.

5.1.6 @HOME for acute cardiac care

This @HOME configuration addresses the acute care needs of patients with cardiovascular diseases. This is achieved through the use of stand-alone sensors, namely the SpO2 sensor (Oxygen saturation level), the ECG sensor and the blood pressure sensor (Figure 5.9).



Figure 5.9: Medical sensors

The architecture of this @HOME version is shown in Figure 5.1 where the medical sensors

used are the biosensors mentioned just above. The patient will be at his home [provision for outdoors use - carrying (or wearing) - is being made] with a medical device that will monitor various health parameters to provide vital data to the doctors at the clinic.



Figure 5.10: System architecture for the cardiac pilot

These sensors are mobile and small enough to be carried in a small carrier bag. Sensors that might offer functionality for outdoor operation will transmit health data wirelessly to the server located at the monitoring clinic (Figure 5.11). Three biosensors are currently addressed in @HOME system:

1. SpO2 Sensor (Oxygen saturation level): This device is able to continuously monitor SpO2 during the night, save the data and transmit it to the hospital once a day. The NONIN XPOD SPO2 is used . In case of an adverse event, it is possible to perform SpO2 measurements at any time of the day. The patient locally and the hospital remotely are both able to initiate an immediate transmission of the collected data.
2. ECG sensor: This is used for the monitoring of segment deviations (ST), rhythm disturbances and heart rate. Continuous monitoring enables the data transmission to take place once a day. The hospital sets up the monitoring range with a minimum duration of 1 hour. The patient himself should be able to trigger data transmissions if s/he feels something's wrong.
3. Blood pressure sensor: With this sensor it is possible to measure the blood pressure several times during the day/night. The OSCAR 2 Oscillometric Ambulatory BP recorder is used . The configuration of the device set-up is done by the hospital (which sets the frequency and the time of measurements). The data transmission is continuous. Once a day transmission is be the minimal expectation. Nevertheless all programmed measurements must be stored for transmission.

Finally, it should be noted that, due to the modular nature of the @HOME platform, a special case of medication adherence measurement for cardiovascular patients and drug trials is also satisfied.

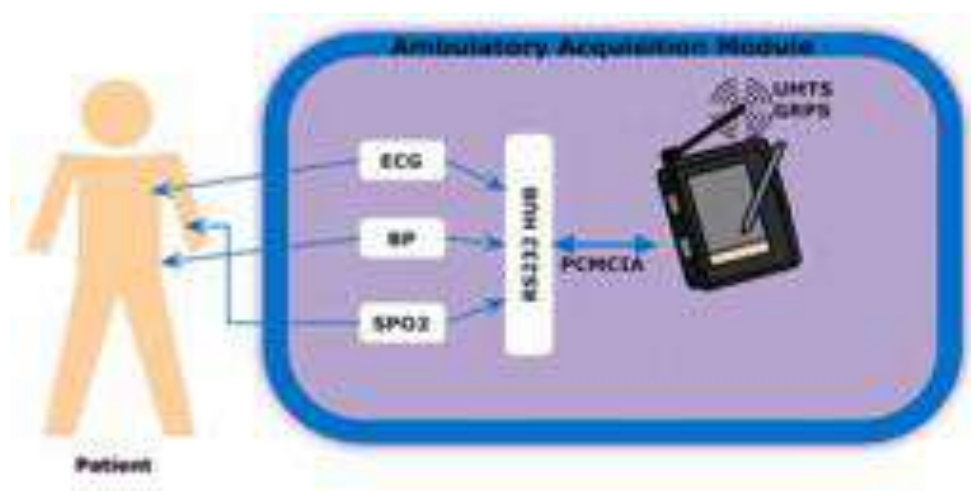


Figure 5.11: Ambulatory acquisition module

The data volume transmitted over the @HOME system in an hour of the system operation are indicated in Table 5.4.

Signals measurements	Sampling rate (samples/sec)	Resolution (Bytes/sample)	Information rate	Data volumes after 1 hour
ECG 1 lead	300	12	3,6 KB/s	12.6 MB
ECG 12 leads	300	12	43,2 KB/s	151.8 MB
Pulse oxymeter (SpO2)	3	24	72 B/s	253.1 KB
Heart pulse	3	8	24 B/s	84.3 KB
Blood pressure	1 per 30 min	32	32 B/s	64 Bytes
Medication events	1 per 30 min	32	32 B/s	64 Bytes

Table 5.4: @HOME data volumes

5.1.7 Results from the cardiac pilot study

Background

Cardiovascular disease is a major global health problem, and the most common cause of death in the western countries. Time spent in hospitalizations for acute coronary syndromes, such as an acute myocardial infarction (AMI) or unstable angina (UA), has currently great implications on the Health budgets. Usually the length of stay in the hospital is between 7 and 10 days for an uncomplicated AMI, and 4 and 7 days for an uncomplicated UA episode. Initial management of these patients is essentially directed to symptom relief. Patients are usually subject to an intensive risk stratification process, in order to better identify those who will most likely benefit from more aggressive and invasive (and more costly and risky) therapeutic procedures. Some of the tests used for risk stratifying patients with an intermediate baseline risk may be performed in an out-of-hospital setting.

However, such a solution is associated with a major clinical concern, i.e. safety of early discharge. Allowing a specific subset of *stable* patients to continue the risk stratification

process out-of-hospital, requires a stable, reliable and innovative ambulatory management system.

Aims

The @HOME solution aims to reduce the hospitalization period of patients with suspected definite acute coronary syndromes and to provide the same monitoring capability that conventional state-of-the-art hospital management would make possible.

Design

The cardiac pilot study is a single-centre prospective controlled study was designed to examine the safety and cost-effectiveness of at-home monitoring (with the @HOME system) of patients discharged early after hospitalization for an acute coronary syndrome.

During the patient recruitment period, all patients admitted to the Coronary Care Unit of Hospital Santa Cruz (UNICOR) were systematically screened for inclusion. According to good clinical practice guidelines, written informed consent was provided prior to inclusion in the study.

Patients aged less than 75 years, with uncomplicated acute coronary syndromes (Q-wave myocardial infarction, non-Q myocardial infarction and unstable angina), who had been submitted to early invasive management including adequate functional percutaneous revascularisation and who were clinically stable by 24 hours after admission, were deemed eligible for participating. The Hospital Ethical Committee approved the study. Written informed consent was obtained from all patients prior to study entry. Consenting and eligible patients were randomized on a 1:1 basis to conventional management or @HOME management. The latter involved an additional 24 hour-stay in the Coronary Care Unit, followed by hospital discharge and a further 24 to 72 hours monitoring at the patient's home. Monitoring with the @HOME system commenced immediately after randomisation in these patients. Thus, the first 24 hours of @HOME monitoring were performed in hospital, and focused on patient and carer education on how to use the system properly.

Additionally, during this period the physician set and pre-tested the system thresholds and set-ups based on individualised medical assessment of the patient's condition.

The central system server (CSS) was set at the IdC. The system provides the doctors with the ability to:

- Customise alerts thresholds for each medical sensor
- Individualise time periods of sensors measurements. It is possible to establish several time-tables for different times of day (Figure 5.12)
- Perform real-time measurements from all medical sensors (Figure 5.13)
- Receive clinical and administrative alerts in real-time
- Use graphical representations to access the stored patient measurements, as well as, to receive the real-time data.

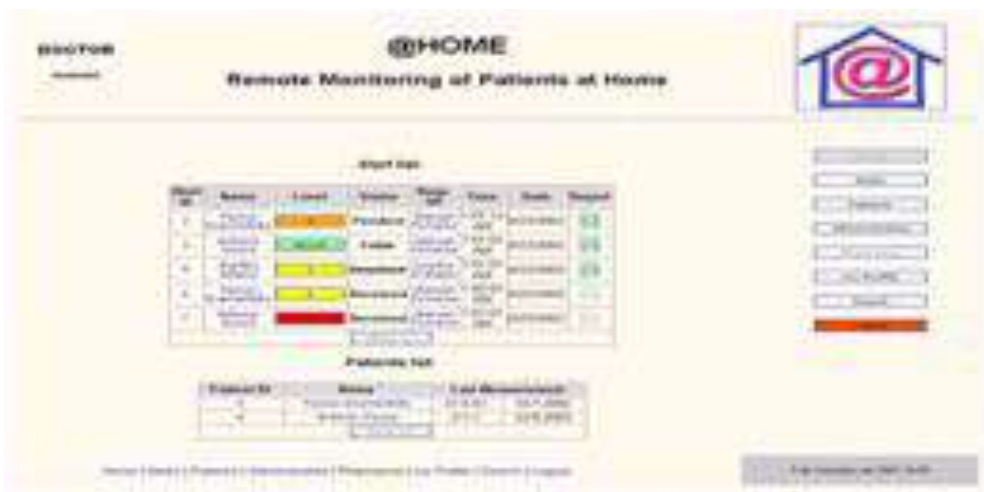


Figure 5.12: Physicians graphical user interface

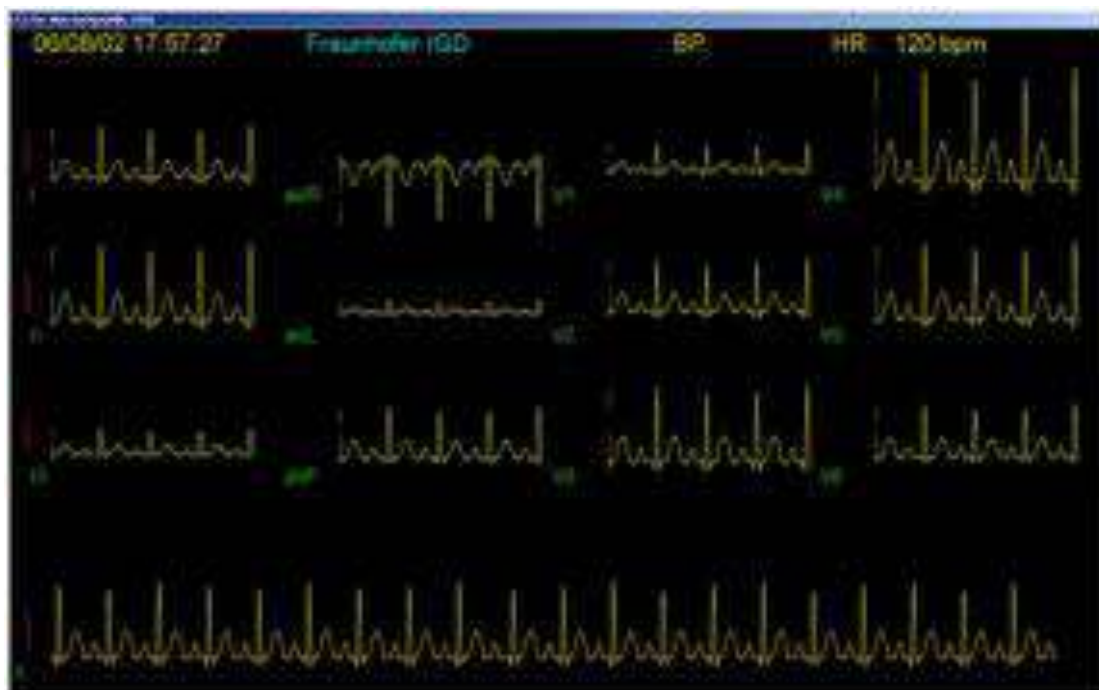


Figure 5.13: ECG real-time acquisition

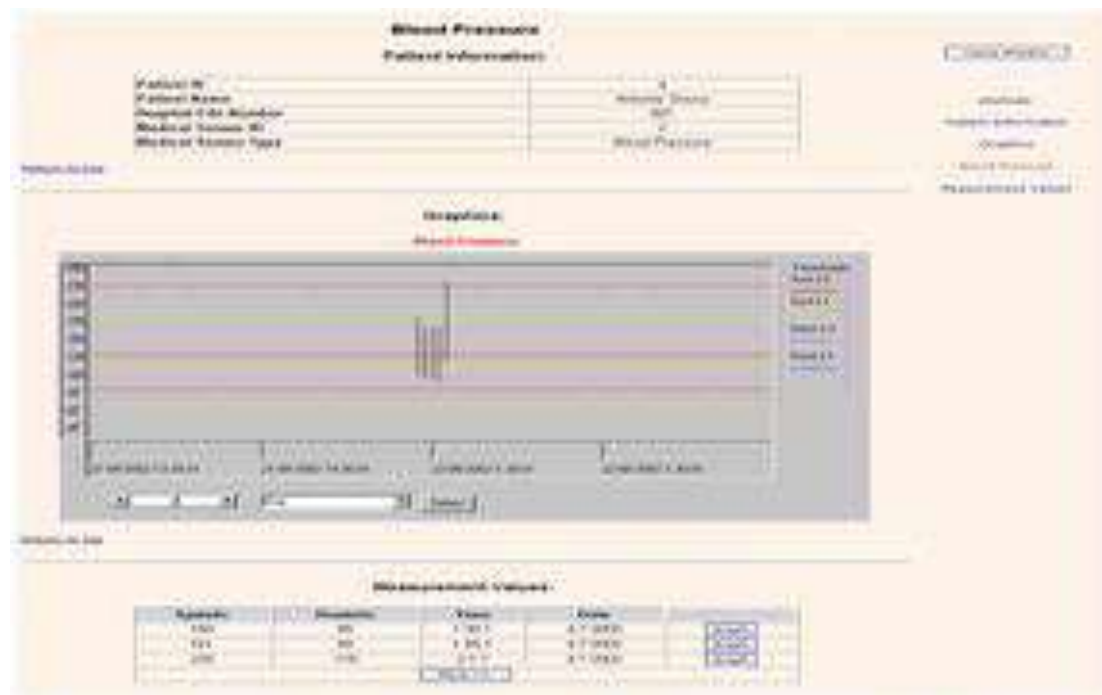


Figure 5.14: Blood pressure measurement presentation

The patients on the other hand:

- Used non-invasive ambulatory medical sensors (Figure 5.14)
- All measurements were performed at pre-established times with the ability for the patient to trigger on-demand measurements
- In case of emergency, patients could press an alert button in the ECG sensor
- Was provided with information about his specific condition, along with useful advices (Figure 5.15)

The @HOME system generated alerts based on patient-specific specifications determined by the treating cardiologists. Alerts were repeated every 30mins until deactivation from the recipient. The alerts reached recipients within 1 hour of the event. A Level 1 alert generated if SpO2 level falls below 88% (default value). A Level 1 alert generated if blood pressure fell outside patient-specific limits. A Level 1 alert generated if heart rate fell outside the 50-120 beats/min. A Level 1 alert generated if the ST segment deviated more than 1,5 millimetres for a period > 1 minute (default value). A Level 2 alert generated if both heart rate and blood pressure readings fell outside the limits. A Level 3 alert generated if all three (SpO2, blood pressure and heart rate) measurements fell outside the limits set. A Level 4 alert generated when an irregularity reported by the ECG occurred.

Two sets of the @HOME biosensors were tested. The average use of the set per patient was around 5 days and 16 patients validated the system.



Figure 5.15: Useful advices presentation

Results from cardiac pilot study

The main outcome measures from the pilot study concentrated on the reliability and safety of the system in real-life clinical situations. Participating physicians reported that the measurements were sufficient to cover their requirements and that they were delivered with speed and accuracy. User interfaces were found user-friendly. Doctors accessed after authorisation (login and password). They chose to view patient activity since last time he/she viewed it. Printing of reports was available. They were able to view relative Word/Excel documents through the interface (Figure 5.16).

It was not possible for the @HOME service to be integrated with other Hospital systems but the latter were accessible and fully functional even when @HOME was running. No problems were identified with data transmission. Patients and doctors were able to see measurements in real time that was clinical helpful for doctors and reassuring for patients and carers. Learning time required for operating the @HOME was estimated to 4 hours on average for the coronary intensive care professionals, which was deemed reasonable.

@HOME technical Innovation

@HOME is innovative in the use of the technology but also in the use and business concept. Many of the individual components that are integrated to form the @HOME system are already present in the market. However, there does not exist a system as complete as @HOME, combining multi-sensors, transmission of the data over wireless links, analysis of the data at the clinic and, closing the loop, feedback to the user. The state of the art and its comparison with the @HOME solution are briefly presented in the following sections. The

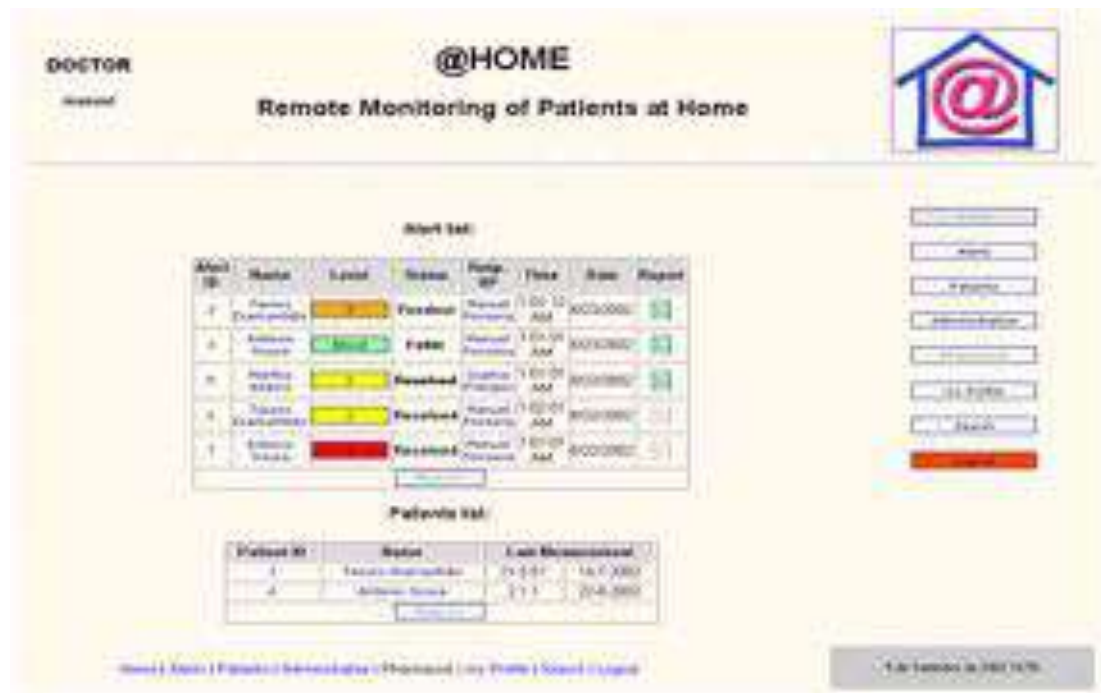


Figure 5.16: Extracting reports for later view in Word/Excel

innovative characteristics of @HOME are summarized in the following:

- Medical sensors.** The current state of the art in medical sensors allows for easy and unobtrusive electronic measurement of several health parameters. All of the above sensors are stand-alone devices, sometimes comprised of two elements connected by a tube or cable, one wearable and the other desktop. @HOME addresses vital parameters through biosensors as ECG, Oxygen Saturation (SpO2) and blood pressure sensors. Alongside those, @HOME introduces an additional sensor, the medication dispenser, which, although not performing any measurement to a physical body element, collects information about the patients' medication adherence behaviour. This is considered as an important feature, because medication adherence enables easier decisions on the treatment procedure modification according to the current medication adherence profile and the current patient status. @HOME will further innovate by integrating the medical sensors together, thus creating multi-sensors, serving the need for quick and easy measurements of several parameters. The Remote Controller will in turn transmit the patient data to the clinic for monitoring by the medical staff.
- Medical Sensors Remote Link.** This is a simple but truly innovative concept for home use. The medical sensors will be integrated with a communications device, which will transmit the patient's data to the clinic for monitoring. The multi-sensors (wearable devices) will be able to function stand-alone and they will be equipped with transceivers, which will allow the patient data to be transmitted to the clinic.
- Home monitoring services.** @HOME will allow for real-time health-monitoring of a patient by specialised staff at the clinic. Home monitoring is not a new concept but there is no product in the market, offering real-time monitoring of vital parameters.

At the most, current applications are highly specialised and are of practically no use elsewhere. @HOME will also feature a fully automated monitoring system with a user-friendly interface. The system will automatically trigger the alarm if the readings of the patient show an abnormality. Finally, the information loop will close with feedback to the patient and the (non-) specialised carers at home. Such services do not currently exist. @HOME will be a pioneering attempts by breaking technological ground and validating the product by conducting clinical trials.

5.1.8 Conclusions

We have shown throughout this project, that partnerships - between companies offering complementary services and products as well as between organizations in the private and public sectors - are both feasible but also mutually beneficial and above all essential for successful development and implementation of e-health solutions.

E-health relates to the collection of electronic healthcare activities under a single roof. Within e-health the new horizons for development are opening up in the area of home-based care and personal health care. The need for such services is fuelled by growing cost restrictions within traditional health providers, forcing them to look for alternative models of care. In addition, health care is going through a era of consumerism where choice and self-determination are more important than ever.

@HOME represents an intelligent response to the growing need for e-health personalised solutions but offering maximum choice, freedom and flexibility to patients without compromise in their clinical care.

5.2 T@LEMED

5.2.1 Introduction

T@lemed - *Evidence based Telemedicine for Remote and Rural Underserved Regions in Latin America using eHealth Platforms* introduced an eHealth model to the provision of health services in strongly underserved regions in Colombia and Brazil.

The implementation of this model was developed on contemporary telehealth technologies as well as on evidence based medicine. The target clinical applications included:

- infectious diseases for the region such as malaria and tuberculosis
- and general ultrasound applications such as pregnancy control, urology and cardiovascular diagnosis

The implemented telehealth networks connect high level health care resources available in capital cities with low level health care facilities in under-served regions. The trial of this model reflected in the deployment and pilot tests of telehealth stations, demonstrated to local health authorities the benefits of information technologies for health provision and social development.

T@lemed consisted of two sub-projects in which two main actions in the two target countries Brazil and Colombia were carried out. The subproject Malaria / T@lemed-Colombia implemented teleconsultation services for diagnoses and treatment of malaria, dermatology and radiology for underserved regions in Colombia by using and adapting an extended version of the telehealth platform TOPCARE that was developed by Fraunhofer Institute IBMT and the Greek partners ICCS and Datamed in the context of the European Commission's IST research and development program Technologies for the Information Society.

In the subproject Tele-Ultrasound / T@lemed-Brazil, teleconsultation services for ultrasound examinations such as OB/Gyn, pregnancy control, urology and cardiovascular diagnosis were implemented for rural hospitals in Brazil, using the enhanced medical imaging system called *TeleConsult* that was developed by Fraunhofer Institute IGD and the German partner Medcom GmbH.

Access to medical care is sometimes very difficult to be reached from people living in rural and under-served areas. This problem is very well known in rural areas in Brazil. Citizens have no access to health care. They have to travel hundred of kilometers to receive a medical diagnosis.

In Brazil there exists a two-tiered system of health care access [111]. Those with sufficient means have access to a private system of health care that provides quality treatment on demand, while the remainder of the country relies on the overburdened system of public clinics and hospitals. The ever increasing size of the poor, elderly population, as well as the increasing cost of treatment for a limited supply of public health care services, suggests that the public health care structure will become even more heavily used in the coming decades. At the same time the poorest segments, which are generally perceived to be rural, black and mixed-race Brazilians are losing access to health care. Since the country is climbing out of recession and struggling for economic stability, government resources are expected to improve, but this is not expected to solve the problem quickly.

Comparing health services provided in rural and urban areas, overall it has been found that utilization is lower in rural areas. A significant factor in lower utilization is that rural residents have less access to health services and that only very reduced specialist care is provided. The different health care needs of large urban cities and tiny rural villages are one of the country's greatest challenges. There is evidence that Brazil's urban poor have slightly worse health than their rural counterparts, prompting demands for improvement in the timeliness and quality of health care.

In the other hand, information technology (IT) is an increasingly important piece of the Brazilian health care puzzle. Though inadequacies in funding, understanding and effective solutions are challenging local health care IT specialists, Brazil is already successfully implementing technologies that promise to make health care easier to manage. The Internet and web-enabling technologies are saving many of the cash strapped health care organizations in Brazil from being overwhelmed with paper shuffling and manual data collection.

The lack of specialist doctors in rural areas forces many patients to travel to urban hospitals for diagnosis and treatment. The existing primary care physicians often need to consult a specialist at Santa Casa Hospital for security and cross checking. Santa Casa hospital, for example, receives an average of 2000 outpatients from rural areas in the interior of Rio Grande do Sul, for whom it performs ultrasound examinations. These are 40% of all 5000 ultrasound investigations performed at Santa Casa per month. Cases that do not require

the transfer to the hospital represent about 30% to 40%. In addition, displacement of the patient to a larger centre always provokes a trauma due to the change of the surroundings, the unknown doctor, the lack of family and friends and often more costs. Certainly these factors and the additional stress have a negative influence on the healing (ability to cure) of the patient. Could the patient stay at his hometown, none of this would happen, remaining only with the precaution of his treatment.

The medical network system proposed by the T@LEMED project brought great benefits to the isolated regions. It made it possible to offer medical aid practiced at the University Hospital to the anchor hospitals of the state without removing the patients from their original area; this is translated into a decrement of the frequency of patient transfer to the capital city, which reduces costs and humanizes the attendance. It increases the disposition of hospitals vacancies in the capital, decreasing the queues to services and hospitals internments.

The tele-health concept is simple and connects remote and isolated regions in Brazil with referral hospitals. Particularly, we focused on the following:

- To early identify and to treat future problems of health (preventive health care in Gyn/obstetrics)
- To treat and early identify systemic problems of health (preventive health care identified by abdomen and pelvis exams)
- To send the patient for treatment already accomplish with the evidenced diagnosis
- Medical training through the continuous contact with specialist of the reference center
- To test if a generalist doctor is capable of using the system T@lemed, with specialist's support for the remote diagnosis
- Medical change of information through the continuous contact between specialists of the different cities (and second opinion)
- To prove that the system T@lemed, can be useful for the remote diagnosis, in prevention and in the treatment

5.2.2 Medical services

T@LEMED in Brazil over TeleConsult medical application offers an imaging health telematic platform for cooperative work and transfer of medical data via a variety of telecommunications channels (phone, GPRS, satellite, Internet, UMTS). The technology allows the transmission and analysis of two dimensional (2D) and three dimensional (3D) medical images. By this, TeleConsult improves the exchange of medical reports, second opinions and treatment options within the physician-to-physician communication. The T@LEMED platform offers the following services:

- **Second Opinion:** Both real-time and store-and-forward collaboration between physicians concerning suspicious patient cases

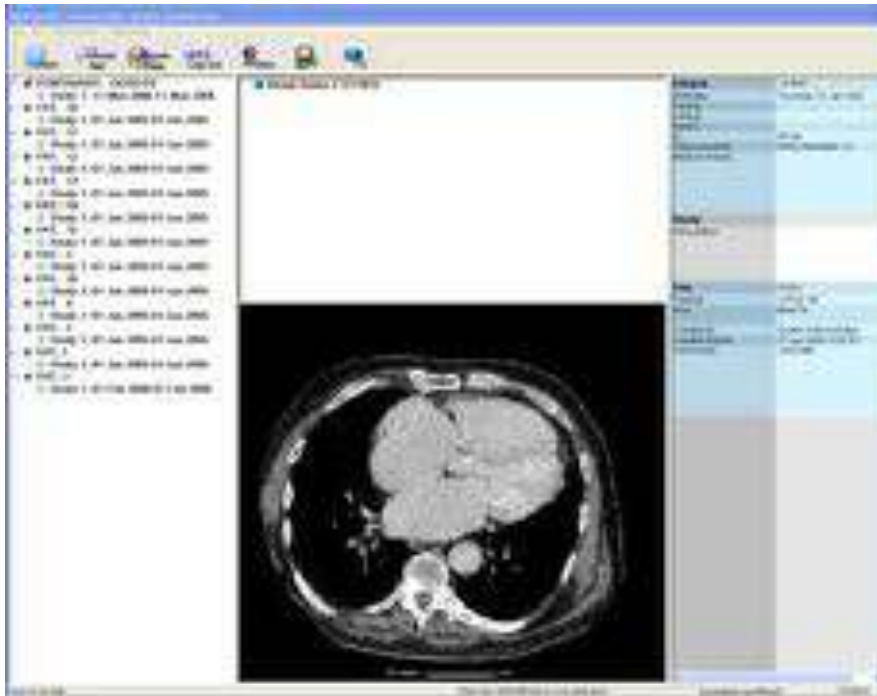


Figure 5.17: Imaging and patient database

- **Remote Reporting:** Sending imaging reports, that can be reviewed by remote physicians either in real time or later, using the system's store-and-forward capabilities
- **Interdisciplinary Communication:** Virtual meetings among doctors from various specializations

Medical imaging collaboration application

TeleConsult/TeleInViVo, developed by Fraunhofer IGD and MedCom GmbH, provides several functions for the construction of a health telematics network. In the connected database patient and image data and all incoming and outgoing messages are stored, as illustrated in Figure 5.17.

In the latest software version a DICOM viewer has been incorporated, making possible the use of the TeleConsult application for other imaging modalities (such as X-Ray, MRI, CT, PET, SPECT images).

Client/server architecture provides the central storage of all data and the access from every PC, which is equipped with the client software. Members of the health telematics network store their data in their local database and send the queries to the consultant center via ADSL or other available communication channels such as Internet, WLAN or satellite. The medical history of a patient, which is necessary for the assessment of a case, is sent anonymously and automatically with the messages.

Data transmission can be performed either in real-time or in store-and-forward mode, as illustrated in Figure 5.19. For the communication among the physicians the jabber protocol is applied. Jabber is an open source instant messaging protocol.

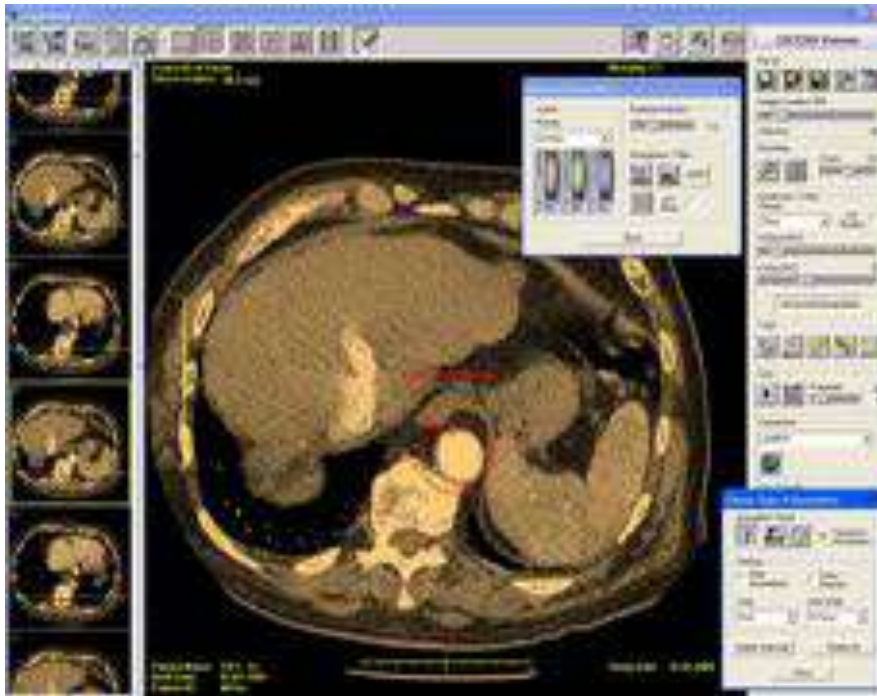


Figure 5.18: CT representation in dicom viewer

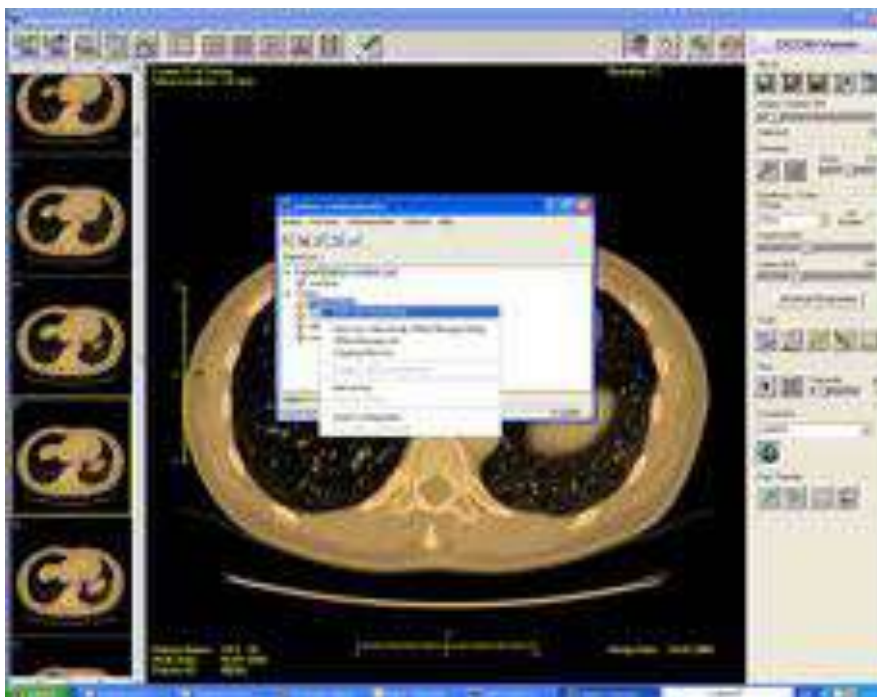


Figure 5.19: Jabber enabled messaging communicator

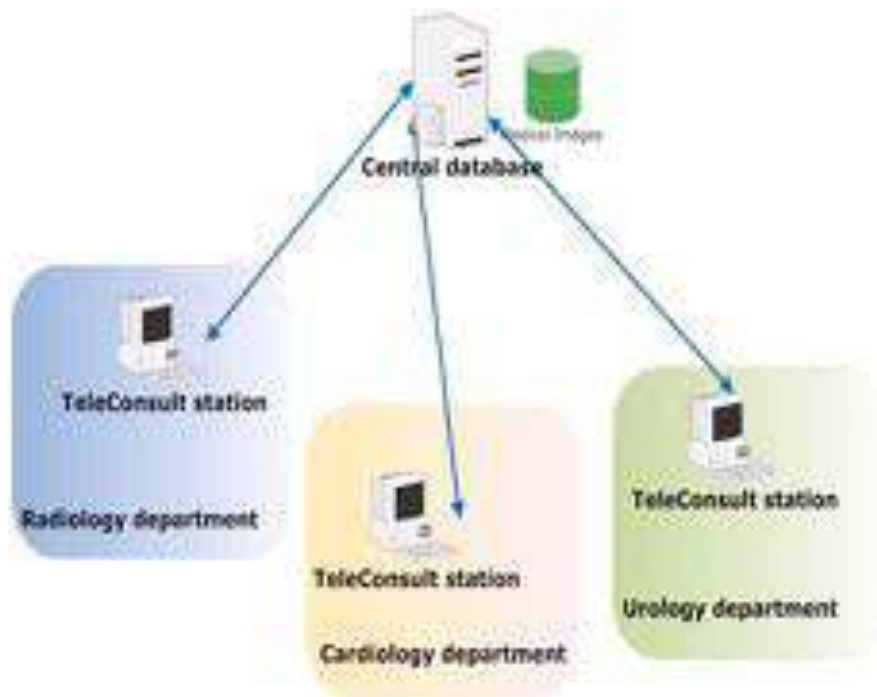


Figure 5.20: Centralize imaging database

Furthermore, direct access to the database is supported and multimedia annotations (cursor movements and voice) are possible, as well as text annotations and chatting. In summary, TeleConsult offers the following features:

- Creating and handling of 2D and 3D images including the acquisition of 2D/ 3D image data and the import of images in DICOM format
- Sending and receiving of messages with text and image material over TCP/IP in real-time or store-and-forward mode
- Enrichment of the images with graphical and textual annotations and pictograms
- In the on line (real-time) mode interactive communication via usage of a chat window, mouse, exchanged images and a shared screen view is possible
- Client/Server architecture of the database. Storage of all images, patients and messages in the database (Figure 5.20)
- Handling of a second opinion service for customers and partners of a health telematics services center

Medical imaging acquisition

The medical collaboration application (TeleConsult) is able to acquire ultrasound images making use of a video frame grabber. An ultrasound device is almost capable of delivering the ultrasound images via an analog video output. The ultrasound analog video output

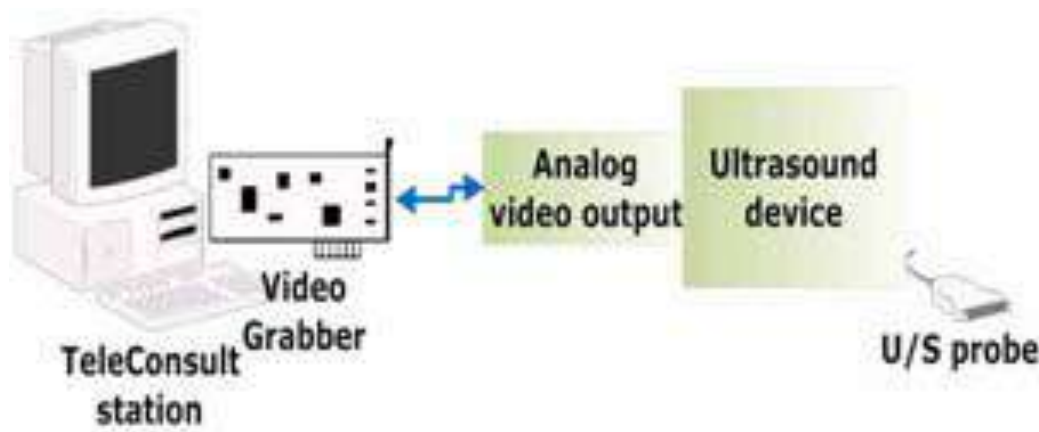


Figure 5.21: Ultrasound image acquisition via frame grabber

is connected to the video grabber that digitizes the analog data. A frame grabber is an electronic device that captures individual, digital still frames from an analog video signal or a digital video stream. It is usually employed as a component of a computer vision system, in which video frames are captured in digital form and then displayed, stored or transmitted in raw or compressed digital form.

5.2.3 Deployment

In Brazil, ten (10) installations took place in Rio Grade do Sul (RGS) and Espitos Santos (ES) prefectures. TeleConsult application deployed in Santa Casa hospital, which is the referral hospital of four (4) remote clinics in rural areas, in Rio Grade do Sul. In details, the system has been deployed at FAHUCAM in ES and Santa Casa hospital in RGS, which is the referral hospital of four (4 + 4) remote clinics in rural areas respectively. Below, we name the connected sites to the medical network:

1. Lagoa dos Três Cantos Hospital - Lagoa de Três Cantos - RS
2. Fundação Ivan Goulart Hospital - São Borja - RS
3. Hospital São Luiz - Mostardas -RS
4. Hospital - Cidreira - RS
5. Hospital - Colatina - ES
6. Hospital Santa Casa - Cachoeiro - ES
7. Hospital - Barra de São Francisco - ES
8. Hospital - São Mateus - ES

In figure 5.23 the interconnectivity of the clinics and hospitals is illustrated.

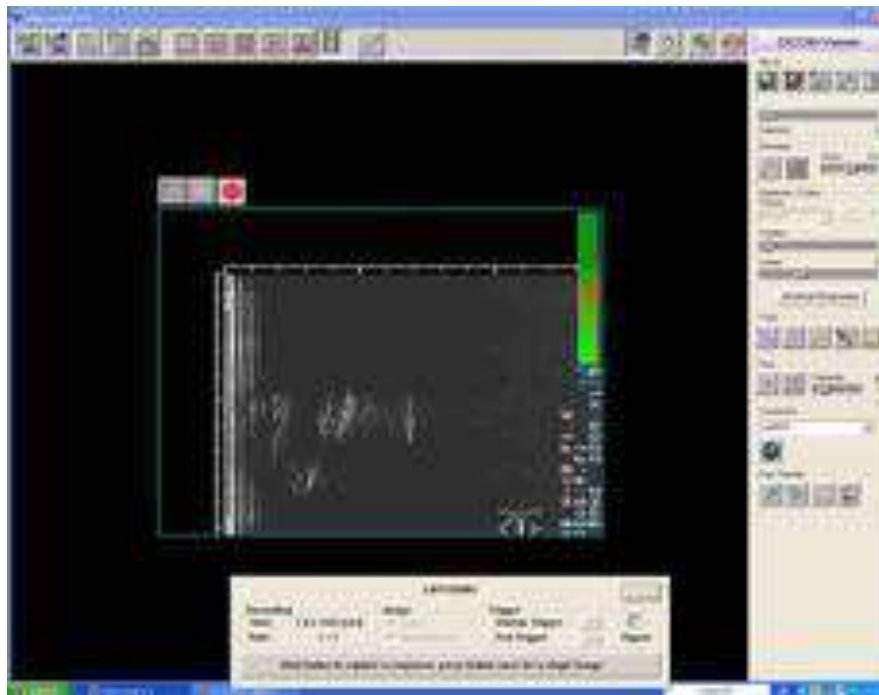


Figure 5.22: Image acquisition interface

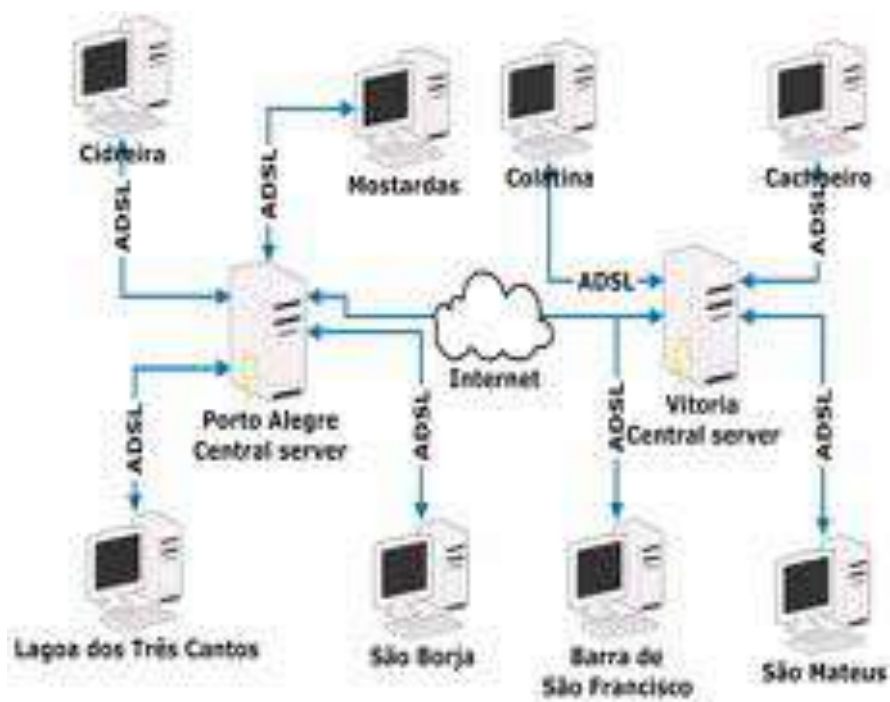


Figure 5.23: T@LEMED hospital and clinics network



Figure 5.24: Radiologist department in University hospital HUCAM, in Vitoria

Pilot network in Espirito Santos

Espírito Santo (ES) is one of the states of the southeastern of Brazil with the capital in Vitória. It has a population of 3.097.232 inhabitants and the total area is 3.097.232 Km^2 .

Based on second opinion on ultrasound image diagnosis, ES network organized with the reference center at the Espirito Santos Federal University HUCAM, on the east side of Espirito Santo, in the island of Vitória and four remote hospitals located in the south (Cachoeiro do Itapemirim), west (Colatina), northwest (Barra de São Francisco) and north (São Mateus).

The University Hospital HUCAM is a general University Hospital and besides medical teaching in health care, develops wide social health assistance. Its assistance focuses on rural populations in the state of Espirito Santo, southern Bahia and east Minas Gerais state, covering a population of more than 3.5 million people. The services range from primary and secondary health care to highly complex surgeries and cases not yet found in the literature, achieving therefore its double function of teaching and assistance (Figure 5.24).

Barra de São Francisco - Dra. Rita de Cássia Hospital

Barra de São Francisco has a population of 42.000 inhabitants and is located 260km far from Vitória (Espirito Santo capital city). The total area is 4.039 km^2 and 54,11% is urban and 48,89% rural. The telemedicine in Barra de São Francisco started in July 2005.

The attendance at Dra. Rita de Cássia Hospital goes beyond the city population and serves as a region hospital for the surrounding area (Figure 5.25), upper Northwest State of



Figure 5.25: Barra de Barra de São Francisco compartment

Espírito Santo, with a population of 180.000. This city is the head of this micro region which involves 4 other cities. More serious cases are directed to the other medical centers in Colatina, the closest bigger city, or Vitória. The hospital performs 3.800 consultations per month.

Clinic Barabani, a private clinic, direct in the same street and in front of the State Hospital, is subcontracted for executing ultrasound examinations. A medical doctor, Denise Barabani, one of the clinic owners is also the physician responsible for diagnostics at the state hospital (Figure 5.26). There is a claim for a second opinion and the improvement of the medical attendance and treatment in the hospital.

No such telemedicine procedures have ever occurred at Barra. When a patient presents an unknown symptom, the patient is instructed to visit a specialist outside the city and let him/her travel long distances. Often persons can not afford to pay for the trip. In a few cases, the state hospital provides an ambulance, but not all cases can be covered.

The network connection at Barra de São Francisco is via phone service and internet, using a radio link of 128kbps with fix IP. The transmission equipment presents instability and is often out of order although the provider always states that these will change. Barra has one computer, Pentium IV (3GHz), 512MB RAM, HD 80 GB, 17 inch monitor and video capture card to link to ultrasound equipment.

Cachoeiro de Itapemirim - Santa Casa Hospital

Cachoeiro de Itapemirim has a population of 1.550.024 inhabitants and is located 129km from Vitória, Espírito Santo capital, where the specialists work. The total area is 4.110,90



Figure 5.26: The physicians performs an ultrasound examination in Barra de Barra de São Francisco

km^2 and is composed of 84,19% urban area and 15,81% rural area.

The attendance at Santa Casa hospital goes beyond the city population and serves the surrounding area, upper South State of Espírito Santo, with a population of 280.074. This city is the head of this micro region which involves 10 other cities. More serious cases are directed to the other medical centers in Vitória. The hospital performs 6.057 consultations per month.

Santa Casa undergoes an infrastructure remodeling of many areas in the hospital, including the radiology area. Not only was an ultrasound equipment acquired, but also a CT. There is mainly a demand for tomography images. In the future, Santa Casa hospital would like to connect a CT tomography system to the telemedicine system for second opinion and diagnosis confirmation.

The network connection at Cachoeiro is ADSL link of 768 kbps with dynamic IP. Cachoeiro has one computer, Pentium IV (3GHz), 512MB RAM, HD 80 GB, 17 inch monitor.

Colatina - Silvio Ávidos Hospital

Colatina has a population of 112.711 inhabitants and is located 135km away Vitória. The total area is 4.387,80 km^2 and is composed of 85,40% urban area and 15,81% rural area.

The attendance at Silvio Avidos Hospital goes beyond the city population and serves as a region hospital for the surrounding area, the upper West State of Espírito Santo, with a population of 411.378. The city is the head of this micro region which involves 6 other cities. More serious cases are directed to the other medical centers in Vitória. The hospital performs 15.000 consultations per month.

The experience of using the hospital's subcontracted companies for medical examinations



Figure 5.27: Barra Cachoeiro de Itapemirim compartment



Figure 5.28: Colatina compartment

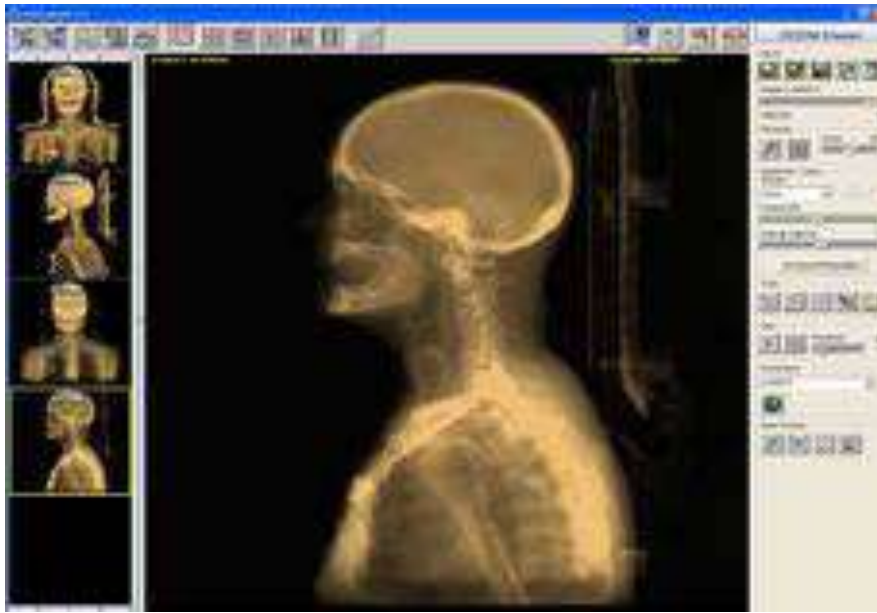


Figure 5.29: TeleConsult viewing an x-ray image

encounters unavailability of physicians time and sometimes no motivation to elaborate.

As for the most state hospitals in Espírito Santo, the lack of technical infrastructure and human resources is significant. There is no ultrasound equipment, CTs, or MRIs. However, the hospital showed a great demand for second opinion on X-ray images (Figure 5.29). Marcio Foletto MD is the physician responsible for diagnostics at the state hospital.

The network connection at Colatina is ADSL link of 512 kbps with dynamic IP. Colatina has one computer, Pentium IV (3GHz), 512MB RAM, HD 80 GB, 17 inch monitor and one digital camera Sony P73 4.1MP.

São Mateus - Roberto Arnalt Silves Hospital

São Mateus has a population of 88.695 inhabitants and is located 220km away from Vitória. The total covered area is 2.343km^2 and composed of 72,12% urban area and 27,88% rural area.

The attendance at Roberto Arnalt Silves Hospital goes beyond the city population and serves as a region hospital for the surrounding area, upper North State of Espírito Santo, with a population of 157.575. This city is the head of this micro region which involves four (4) other cities. More serious cases are directed to the other medical centers in Vitória.

The network connection at Sao Mateus is a link of 512 kbps with fix IP. Sao Mateus has one computer, Pentium IV (3GHz), 512MB RAM, HD 80 GB, 17 inch monitor and video capture card for link to US-Equipment.



Figure 5.30: São Mateus compartment

Installation overview in Espiritos Santos

All pilot sites had a communication channel of ADSL 512Kbps for using Teleconsult, except for Barra de Sao Francisco that has a radio link 128Kbps.

The telemedicine project in Cachoeiro de Itapemirim, Colatina and Barra de Sao Francisco started in July 2005. Barra had problems in communication radio links, so this problem stop the service for two months. The remote site Sao Mateus started in September 2005 and stopped in November 2005 due to an US equipment failure. The US-service restarted again only in August 2006.

Pilot network in Rio Grande do Sul

Santa Casa hospital is a general hospital located in Porto Alegre, the capital city of Rio Grande do Sul (RS) state. The hospital has expertise in all medical areas. Particularly, Santa Casa is composed of seven (7) hospitals and a capacity of 1.257 beds. The hospital receives patients coming from Porto Alegre and other towns of Rio Grande do Sul state. It is estimated that ca. 43% of the total patients of Santa Casa come from others cities and states.

Many patients are transferred to Santa Casa hospital in Porto Alegre for diagnosis and treatment due to the lack of specialist medical doctors, as well as due to the lack of proper medical equipments in the towns located in the countryside.

On average, Santa Casa performs 5.000 ultrasound examinations per month, from which 2.000 patients come from other cities. It is estimated that 30% to 40% of transferred



Figure 5.31: Radiologist team in Santa Casa hospital, in Porto Alegre

patients do not need to be transferred to the capital for diagnosis. They could be treated at the local hospitals in the countryside. In Figure 5.31 the team of radiologists of Santa Casa hospital in Porto Alegre is shown.

The transportation of these patients to Porto Alegre has the following disadvantages:

- A delayed diagnosis since the patients could be attended earlier in their home town
- Traumas due the changes of surroundings, the unknown MD, the lack of family, friends, stress and transportation cost to the patients and sometimes also to the family accompanying them
- Risk for the patients during the transport. The duration of the trip and the bad conditions of the roads
- The utilization of the hospital capacity that could be used for another patient that really needs the specialized care

The chosen pilot cities have different characteristics in terms of size, structure, and availability of diagnostic equipments. The four pilot cities are located in different geographical regions as illustrated in Figure 5.32.

Throughout the pilot period the following ultrasound examinations were performed:

- Abdomen and pelvis examinations
- Gynecology and obstetrics examinations

Different and complementary qualified teams at Santa Casa hospital - Centre of Reference-provided medical second opinion to the aforementioned type of examinations.



Figure 5.32: Four pilot cities Rio Grande do Sul State



Figure 5.33: Dr. Marcus Dalsasso exams a patient in Lagoa Tres Cantos

Lagoa dos Três Cantos

This city has one medical doctor working exclusively to treat the population of Lagoa dos Três Cantos. Lagoa dos Três Cantos has a small population and the medical doctor has a personal relationship with his patients and the physician plays the role of a family doctor.

Dr. Marcus Dalsasso, a general practitioner (GP), provides medical care to the population of the city maintaining a routine of preventive medicine and directing more serious cases to the other medical centers in bigger cities or to the Porto Alegre hospital (Santa Casa hospital). In Figure 5.33 we can see the physician performing an ultrasound examination.

Lagoa dos Três Cantos city has 1.560 inhabitants, with only one health care center without any imaging equipment. In 2000, Lagoa dos Três Cantos implemented a health care administration system, so called *Love for Life*, that focuses on preventive medicine. The mayor of the city believes that prevention is the best treatment.

The main goal of this health program, *Love for Life*, is to use prevention to minimize the number of patients. At the same time, a constant monitoring improves the citizens' quality of life. All citizens are registered in a local medical database. Through this information the physician can monitor the population's health and the Health Secretary Agency (public health system) can implement public health plans and policies.

In Lagoa dos Três Cantos the main goal of the T@lemed system is prevention (i.e. preventive health care). The motivation for preventive diagnostics follows a simple rule: it is cheaper to prevent illness than to heal a patient, where the patient does not need to be moved for treatment. Besides that preventive health care improves the quality of life.

The initial study of ultrasound was in the area of the abdominal cavity (abdomen and

pelvis) applying for the other parts of the body during the project.

The physician had no ultrasound equipment and no experience working with ultrasound devices at the beginning of the project. However, the physician attended a course of specialization for 10 days on ultrasound acquisition and examination in São Paulo and a practical training in Santa Casa hospital with the ultrasound team to learn the practical use of equipment. Furthermore, the clinic of Lagoa dos Três Cantos managed to acquire a ultrasound equipment for running project's pilot.

São Borja

São Borja has population of 66.086 inhabitants and is about 750 km away from the capital city Porto Alegre. São Borja's Hospital Ivan Goulart specializes in obstetrics and pediatrics.

In 2003, the hospital performed 566 ecography examinations per month on average and attended 95 births per month on average. Dr. Milton Lopes is the MD radiologist of the hospital and responsible for the T@lemed pilot in São Borja. He is a medical doctor specialized in radiology, registered in the Brazilian council of radiology. He is a doctor employed by the hospital that works in small towns near to São Borja, such as Garruchos, Machambará, Itaquarubi, Santo Antônio das Missões. In these places no ultrasound equipment is available and the patients are forced to visit São Borja's Hospital Ivan Goulart to be submitted to the ecography examinations.

In São Borja's Hospital Ivan Goulart when the physicians need a second opinion they call an expert at Santa Casa hospital in Porto Alegre. There was not any formal or organized system of telemedicine or teleconsulting before we introduced T@LEMED.

In some difficult cases or when the local physicians have any doubt about the case, the patient is taken to Santa Casa hospital, in Porto Alegre. Many of the patients that are transferred to Santa Casa hospital do not need to be transferred. Because of that, Santa Casa's capacity is overloaded and the time for the patient diagnostic is extended. Thus, it was expected that the telemedicine system could improve the primary care in general and avoid the displacement of many patients to another larger centers.

The initial study of the ultrasound application was in the area of the Gynecology/Obstetrics and abdominal cavity (abdomen and pelvis) applying for the other parts of the body during the project. The available ultrasound equipment is HP Powervision with 3 multi-frequency transducers. The communication link was implemented over an internet connection via ADSL.

Mostardas

The population of Mostardas is 9.303 inhabitants. The town is located in the east of the State of Rio Grande do Sul and is about 205 Km away from Porto Alegre. The total area is 1905 Km². Mostardas is treated as an isolated city due to the bad condition of the roads particularly during the rainy seasons.

The only hospital of the city is Called Hospital São Luiz, and it has only one ultrasound equipment: Shimadzu, SDL-310A model, type 12Bx1001, monitor 14 inches. The Hospital has ADSL internet connection.

Pilot	Hospital	Type of Images	Telediagnosis
Barra de Sao Francisco	Rita de Cassia	ultrasound	55
Colatina	Silvio Avidos	x-ray	112
Cachoeiro do Itapemirim	Santa Casa	tomography	144
Sao Mateus	Roberto Arnalt Sil- vares	ultrasound	19
		Total	330

Table 5.5: Espiritos Santos network utilization in a period of 12 months

The local medical doctor is named Dr. Ricardo Hoss and is a radiologist. The initial study of ultrasound was in the area of the abdominal cavity (abdomen and pelvis), with the possibility to applying for the other parts of the body during the project.

Cidreira

The fourth pilot city is Cidreira that is located in the coast land of the Rio Grande do Sul state and has the population of 11.300 fixed inhabitants. The population increases during the summer season. In addition, the demand for health care services increases during summer season, too. During summer the population can reach almost 300.000.

The main opportunity presented by the Health Secretary of Cidreira was the installation of the telemedicine system in the municipal health centre that operates 24 hours per day and is dedicated also to emergency cases.

The city has a radiologist medical doctor (Dr. Paulo Barquete) who is capable operating ultrasound devices. At the beginning of the project, he city had no ultrasound equipment. The Health Secretary Agency approved public funds for an ultrasound equipment procurement. The purchase process was concluded with some delays, however the equipment was purchased and the pilot started. The Health Secretary Agency of the city also installed ADSL connection at the health centre.

The medical examinations focused on the area of Gyn/Obstetrics and abdominal examinations including emergency cases.

5.2.4 Results

The utilization of the deployed network in Espirito Santos state in Brazil showed a utilization of 8 teleconsultations per week for all four connected sites. The statistics for each place for the period from July 2005 to August 2006 with the referral hospital center Hucam are shown in table 5.5.

The total data volume of the data exchanged between the sites are shown in table 5.6

From August 2004 until July 2006, 385 ultrasound cases were subject for consultation and diagnosis.

Hospital	Type of Images	Data volume(MB)
Barra de Sao Francisco	U/S	126.5
Colatina Silvio Avidos	X-rays	448
Cachoeiro do Itapemirim	CT	16.020
Sao Mateus	U/S	61.7

Table 5.6: Network data volumes

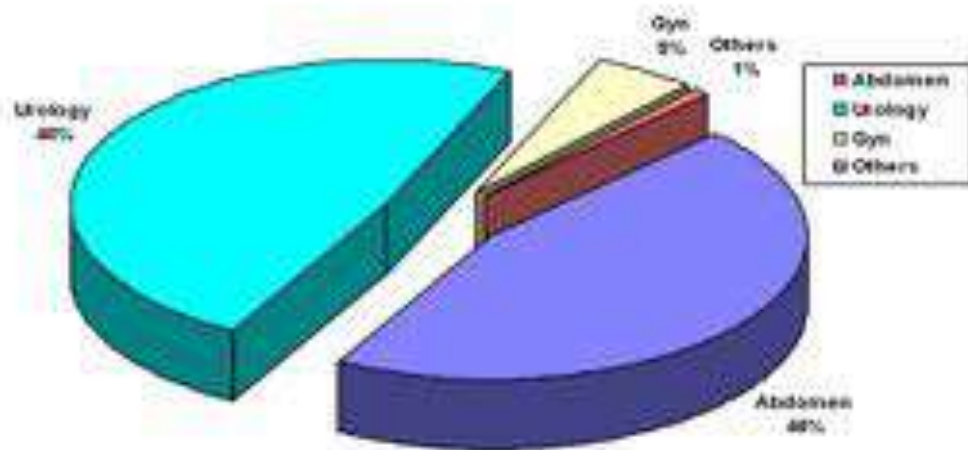


Figure 5.34: Distribution of medical examination in Lagoa Tres Cantos

There were totally 569 reported cases performed in Lagoa Tres Cantos from which 261 required teleconsultation with the radiology department of Santa Casa hospital in Porto Alegre. The distribution of the medical examinations is illustrated in Figure 5.34

In Figure 5.35 the physician acquires ultrasound images and the same time makes visual annotations on the acquired images (Figure 5.36).

The São Borja Hospital has a radiologist who exams 15 to 20 patients a day from which 92 required teleconsultation with Santa Casa hospital.

In Mostardas hospital there were 30 reported cases that required teleconsultation with Santa Casa hospital in Porto Alegre.

In Cidreira, only 2 cases where sent to Porto Alegre, one hepatic, the other renal.

5.2.5 Conclusions

On average Santa Casa hospital performs 5,000 ultrasound examinations per month, from which 2.000 patients come from other cities. It is estimated that 30% to 40% of transferred patients do not need to be transferred to the capital city for diagnosis and treatment. They could be treated at the local hospitals in the countryside.



Figure 5.35: Performing an ultrasound examination



Figure 5.36: Visual annotations on ultrasound images

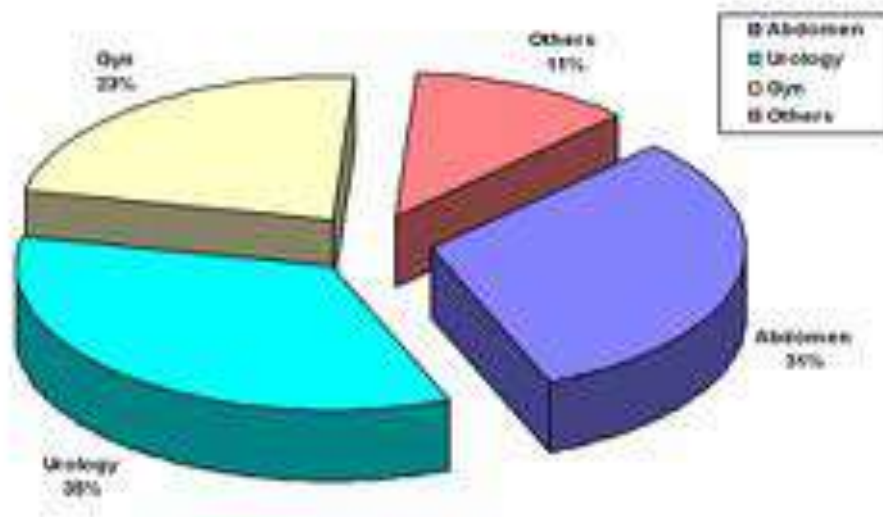


Figure 5.37: Distribution of medical examination in São Borja

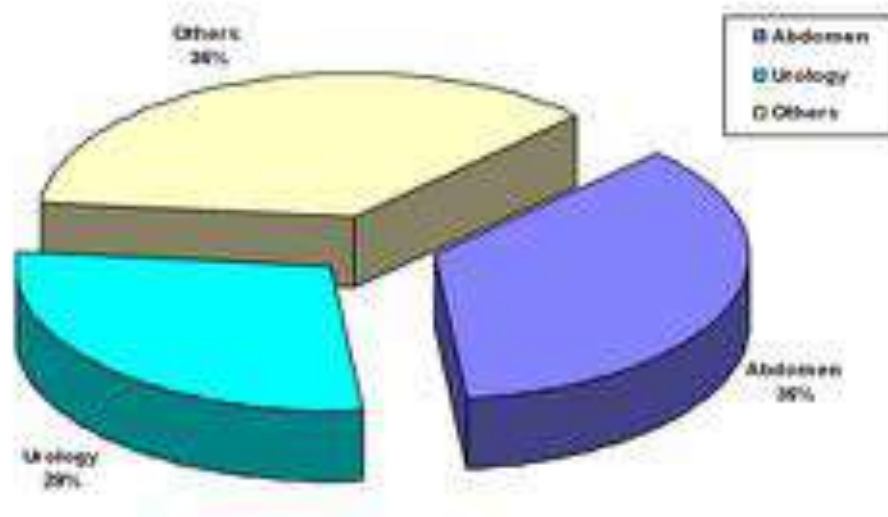


Figure 5.38: Distribution of medical examination in Mostardas



Figure 5.39: Fetal profile in 2D viewer

Bearing that in mind, the proposed imaging medical network tried to minimize the number of patients transferred to Santa Casa hospital and FUHACA hospital -referral hospitals in urban cities-. The teleconsultation platform allowed an optimum classification of the patients who actually need to be transferred and the patient that can be treated by local doctors with the help of a distant expert doctor.

The impact of the telemedicine application deployed is high, particularly for the remote and isolated cities. The system proved to be useful and to speed up the diagnosis. In addition, the physicians of the remote cities benefited from the constant communication with the expert physicians of the referral centers.

Within T@lemed project the medical services provided were based on ultrasound, CT and X-ray images. Throughout the execution of the project, hardware and software was provided to remote sites. All involved physicians were trained to medical imaging collaboration application. The physicians mainly used the 2D version of the application (Figure 5.39)

Professionals of the Rio Grade de Sul network believe that the cost benefit of the telemedicine based in ultrasound images is very high shorting the time of diagnosis. Moreover they strongly believe that the medical network should expand to medical service for computer tomography (CT). The concept of telemedicine based on CT images appears to be more attractive.



Figure 5.40: Para state in northern Brazil

5.3 T@HIS

5.3.1 Introduction

T@HIS was a telemedical network connecting physicians and hospitals over a new generation satellite network based on the recently launched AmerHis payload on the AMAZONAS satellite.

Within the project, three remote clinics in Amazonas, Para states in Brazil, were connected to a referral hospital in Porto Alegre, the capital city of Rio Grande do Sul, in southern Brazil. The dominant type of images transferred over the system were ultrasound images, acquired from portable and stationary ultrasound devices. The medical applications included both obstetric and gynecology examinations. Ultrasound imaging was used. Furthermore, the deployed application was able to handle any imaging modality and particularly DICOM formatted data.

T@HIS was an ESA (European Space Agency) funded project aiming for the evaluation and assessment of medical network enhancements for rural and isolated regions in Latin America based on an advanced satellite communication system (AmerHis).

The Pará State is located in the very north of Brazil and has 143 cities, 6.695.940 inhabitants and represents 16.66% of the Brazilian territory and 26% of the Amazon Region. Figure 5.40 depicts the state of Pará and its borders and the biggest fluvio-marine (river and sea) island of the world, Marajó Island.

The demographic density of the State as well as of the whole northern region in Brazil is too low (huge territory, and proportionally few people). The capital city is Belém. Belém



Figure 5.41: A view of Portel port

has a population of 2.085.000 inhabitants. The main reasons of mortality are the following:

- blood circulation diseases
- birth associated diseases
- breath associated diseases
- infectious diseases
- external causes

The children mortality is about 20 to 49 cases in 1.000 inhabitants per year. Some common diseases are diarrhea, malaria, tuberculosis, typhoid, hepatitis, leptospirosis, yellow fever, tetanus. It's estimated that 35% to 40% of the total medical cost of the cities are expended in treatments in other urban centers. Besides that there is a great lack in human resources availability at the remote areas where a large part of the population lives in poverty (Figure 5.41 and 5.42). The high-complexity medical services are totally concentrated in the capital city, Belém.

The lack of infrastructure and specialist doctors in remote areas forces the transportation of many patients to hospitals in the metropolitan area of Belém for diagnosis and treatment. The distance between the capital city and the rural areas are large, from 200 Km to 600 Km (Figure 5.43).

Roads are not available and the only mean for traveling is by boat or by small airplanes. The traveling duration is estimated around 14hours to 30hours by boat. More details are given in table 5.7.

In order to deal with these problems, the Pará State Government started a telemedicine project including medical tele-consultations for the remote areas and for some indigenous people, as shown in Figure 5.44.



Figure 5.42: Small houses along the Amazon river



Figure 5.43: Rural areas are very distant from the capital city

	Belem	Breves	Portel	Gurupa
Belem	0h	14h	18h	24h-30h
Breves	14h	0h	3h	15h
Portel	18h	3h	0h	14h
Gurupa	24h-30h	15h	14h	0h

Table 5.7: Travel duration between the pilot cities in Para states



Figure 5.44: Isolated areas in Amazon

The region of Marajó island will be the start of this pilot. The island is located at the delta of the Amazon river and covers almost 50.000km^2 . In the region of Marajó island lives 250.000 citizens. The island is surrounded by the Amazon and Tocantins rivers and by the Atlantic Ocean.

Marajó is the largest fluvio-maritime island of the world and is larger than Switzerland or Holland. Its climate is hot and humid and the average temperature is 27° Celsius. Part of the island is flooded from February to April, when half of the year's rain falls. There are 17 municipal districts. Just one of the districts, the one in the east, is open to the tourist and it is easy to access.

Many cities of the Island like Breves are 12 hours far away from Belém by boat (Figure 5.45), the only feasible way to reach the island. In addition, small airplanes can be landed on green fields, if necessary.

In the Marajó Island, the city of Breves has a hospital center that assists almost all the cities nearby. Ultrasound examinations are performed regularly. Typically the people who live on the islands in small villages (*ribeirinhos*) have to travel long distances and travel for hours to access the primary health care services, available on the main cities of the island. In more complex medical cases the patient has to be transferred to a hospital in Belém.

In total, three remote areas in Amazon will be connected through satellite link with a referral hospital of Santa Casa, in Porto Alegre in southern Brazil.

5.3.2 Imaging collaboration application

TeleConsult is a stand-alone application running on Windows 2000/XP. The application is able to acquire medical images from any ultrasound device through a video grabber attached to the computer. Furthermore, DICOM-based agents would store medical images from any DICOM compliant device (DICOM is a worldwide standard for the representation of medical imaging data).

Our medical imaging application is called TeleConsult application is a combination of a 2D/3D DICOM Viewer, an image grabbing software, medical annotation tools and a medical telecommunication tool. Figure 5.46 illustrates the user interface of medical imaging



Figure 5.45: Typical transportation mean in Amazon rivers

collaboration application. The largest part of the user interface is used for the display of the images. On the left side of the software all images, currently loaded into TeleConsult are listed. In the centre of the user interface, there is place for showing the details of one or more images.

TeleConsult makes use of Jabber communicator for exchanging medical information among the physicians, as illustrated in Figure 5.47.

5.3.3 System collaboration aspects

Communication partners in different networks often protect their network through firewalls. As for this reason outbound connections are possible but inbound connections are blocked, if not requested before. The Jabber server serves as a destination for outbound connections and provides a central terminating point for establishing 2-way connections (Figure 5.48).

By starting a jabber session every client logs in with his jabber ID. The jabber protocol is as for every time there is awareness of the availability of the users.

This means that by sending a message from TC User 1 to TC User 2, the server either routes the message directly to user 2 in case of online collaboration or preserves the message if user 2 is in offline mode.



Figure 5.46: Ultrasound dataset in 2D viewer



Figure 5.47: Jabber communicator for data exchange

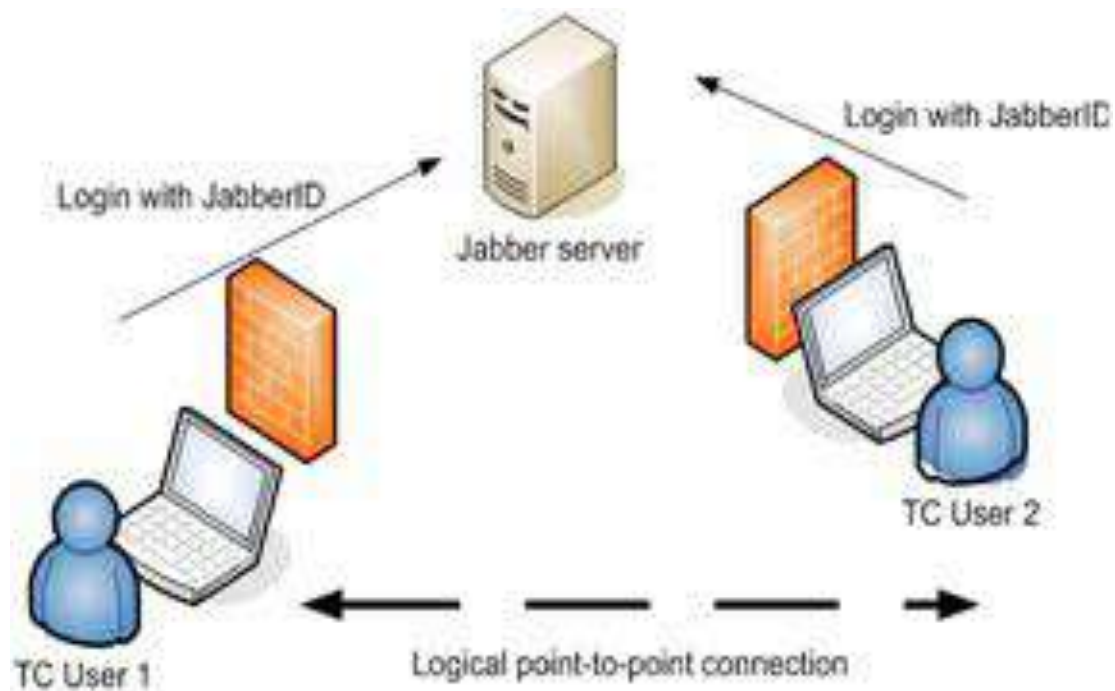


Figure 5.48: Logical point-to-point connection via a jabber server

Online Communication between two TeleConsult Workstations

In the case of online communication, both users are simultaneously logged in at the jabber server. For the person at the remote side, the connection goes over one satellite hop to the jabber server that is located in Belem and from there via LAN to the consulted expert, also situated in Belem.

The on-line communication between two TeleConsult workstations is implemented over TCP/IP based point-to-point connections. Above the fourth OSI layer, again an internal protocol is used (Figure 5.49). Images must only be exchanged, if they are not already in the Database of the remote communication partner. For the synchronisation of the two connected applications, only short commands are sent. This makes it possible to make online consultations even over connections with a low bandwidth. In this case, it is recommended to send the images before the consultations via an offline message.

Figure 5.50 shows the workflow of an on-line consultation. Thereby actions with a dashed border around them are optional. For example, because there is the possibility of auto-acceptation, the request for a connection and the receiving of images can, but must not, be confirmed. If the remote user has already loaded the same image as his communication partner, it is not necessary to send images during the online consultation. Otherwise an image must be sent, so that both users can see the same.

Off-line Communication between two TeleConsult User

In the case that the expert physician is in off-line mode, no direct communication route between physician and expert can be established. In this case the messages are preserved

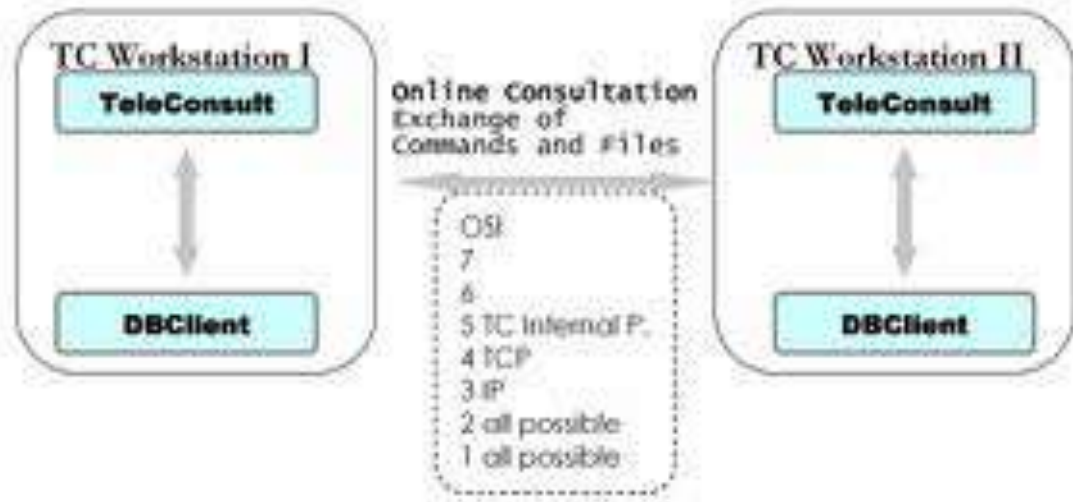


Figure 5.49: Online Consultations between two TC Workstations

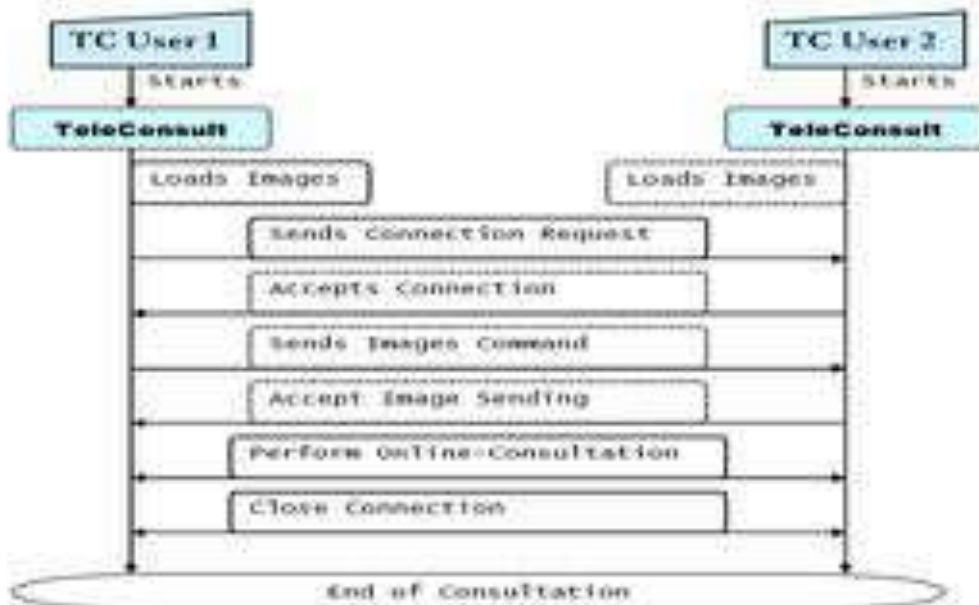


Figure 5.50: Workflow of an Online Consultation



Figure 5.51: Amazonas telecommunications satellite. The satellite offers communications, Internet and broadband services to Latin America

by a jabber server and delivered to the expert by changing in on-line mode.

The jabber server is located in Porto Alegre. The server is accessible from every remote station via satellite and from Porto Alegre through the hospital network. Every TC user connects to the server before starting the collaboration. In the case of off-line collaboration the server knows that the receiver of the message is not in on-line mode, because he is not logged in at the jabber server. So he preserves the message until the addressed user logs in. The TC user gets informed that an off-line message is waiting on the server and he can fetch this message

5.3.4 AmerHis

The selected regions in Amazon have no access to broadband communications. Therefore, AmerHis system is going to be utilized. AmerHis is making use of DVB-RCS bi-direction European standard.

Thales Alenia Space España led the AMERHIS project. AmerHis is an advanced communication system supported and co-funded by European Space Agency (ESA) and the industry to deploy an advanced communications system based on a regenerative payload on board the Amazonas satellite (Figure 5.51).

The AMERHIS system integrates a broadcasting multi-media network with an Interaction network by combining two standards, the DVB-S and DVB-RCS, into one unique regenerative and multi-spot satellite system. In this manner, the users calling for broadband and interactive services will be able to utilize standard stations (RCSTs) at both transmitting



Figure 5.52: AMERHIS full multi-beam cross connectivity

	AMERHIS bandwidth
Uplink	
	0.5, 1,2 and 4 Mbit/s
	DVB-RCS compliant
Downlink	
	54 Mbit/s
	DVB-S compliant

Table 5.8: AmerHis bandwidth specification and protocols

and receiving sides. Figure 5.52 illustrates the concept.

In this system, the DVB-RCS return channel standard is applied by all users to access through a standard uplink to the satellite. On board, the regenerative payload (OBP) is in charge of multiplexing that information from diverse sources into one or more DVB-S data streams capable of being received by any standard IRD equipment. The on board repeater is not only capable of multiplexing signals coming from the same uplink, but also cross-connecting and/or broadcasting channels coming from separate uplink coverage areas to different downlink coverage areas. The bandwidth of the uplink and downlink presented in Table 5.8

AmerHis architecture

The AmerHis system architecture includes the following elements:

- OBP (On-Board Processor)
- MS (Management Station)
- RCST (Return Channel Satellite Terminal)
- RSGW (Regenerative Satellite Gateway)
- VSP (Video Service Provider)
- STB (Set-Top Box)

OBP (On-Board Processor)

The OBP combines DVB-RCS and DVB-S standards into a single multi-spot satellite system allowing cross-connectivity between different uplink and downlinks thanks to the signal processing on board. Providing the packet-level switching and multiplexing, it is designed to physically support the IP Multicast on-board. The OBP payload supports being configured from the management station or through the standard (TM/TC) channel.

MS (Management Station)

The MS manages all the elements of the system. It also controls the sessions, resources and connections of the ground terminals. It is composed of: NMC (Network Management Center), in charge of the management of all the system elements. NCC (Network Control Center), which controls the Interactive Network, provides session control, routing and resource access to the subscriber RCSTs and manages the OBP configuration. . The NCC can directly transmit to the satellite the signaling and timing information for network operation by using the same DVB-RCS standard and receiving the different return channels via DVB-S signal. NCC-RCST, the satellite terminal of the MS, supports modulation and demodulation functions to access to the satellite.

RCST (Return Channel Satellite Terminal)

The RCST (or simply terminal) is the interface between the System and external users. These terminals are able to work in transparent or in OBP-based systems by a simple change of software. In OBP-based systems they allow different kinds of connectivity: single satellite-hop mesh (unicast and multicast) connections, single satellite-hop connections with ISDN through the RSGW and single satellite-hop connections with terrestrial IP networks (Internet, Intranet). In order to provide more complete Triple Play or Corporate services the RCST can have different equipment attached to it.

RSGW (Regenerative Satellite Gateway)

The RSGW (or simply gateway) provides interconnection with terrestrial networks (ISDN/POTS, Internet, and Intranet). At the same time, it manages all its subscribers, guaranteeing their Service Level Agreement (SLA). The RSGW will, as well, establish point to

multipoint connections to provide a dynamic Star Multicast Service. The same equipment that can be added to the RCST for Triple Play can be added to the RSGW (it can reach a transmission rate up to 8 Mbps).

VSP (Video Service Provider)

There are two different types of VSPs that can broadcast DVB-S TV or IP TV to an end-user:

- Transparent Video Service Providers: classical broadcasting stations.
- Regenerative Video Service Providers: low cost micro-broadcasters.

It broadcasts video contents directly to end-users with a commercial set-top-box. It consists of two elements: Content Service Provider: it contains not only the video but also applications to be broadcast. It uses new codecs as H.264 and MPEG4 (apart from MPEG2) that reduces the bandwidth needed in the air interface.

Terminal (SP RCST): it is in charge of transmitting all the data to the air. It must minimize jitter and delay as the main traffic is video on real time. It shares the same hardware of a normal RCST but with different software. It may include another element for the transmission of applications to PCs with a DVB-S card: an Application Download Server (sometimes it is also called Software Download Server). The VSP multiplexes this data with the normal video in the transmission as private data.

STB (Set-Top Box)

In our system two different types of STBs available in the market are supported (the STBs used are completely commercial and they are not special for AmerHis):

- DVB-S STB: the classical receivers for satellite digital TV for native DVB-S video
- IP STB: they are able to receive IP TV with many more interesting features of interaction with the end-user

In both cases new codecs used by the VSP are integrated: H.264 and WM9 are added to the MPEG2.

5.3.5 Medical Imaging Network Deployment

The deployed telemedicine network consisted of three small hospitals in Amazon (northern Brazil) and one referral hospital centre in Porto Alegre (southern Brazil), which provide tele-medical services over satellite communication, as shown in Figure 5.53.

Before the real deployment of the telemedicine platform, the platform was completely tested in order to identify any obstacles in communication on the medical application.

As soon as we had finished with the test-bed, we started with the real deployment and installing the satellite terminals and medical application to Santa Casa hospital in Porto Alegre and Breves city hospital in Para state (Figure 5.54).

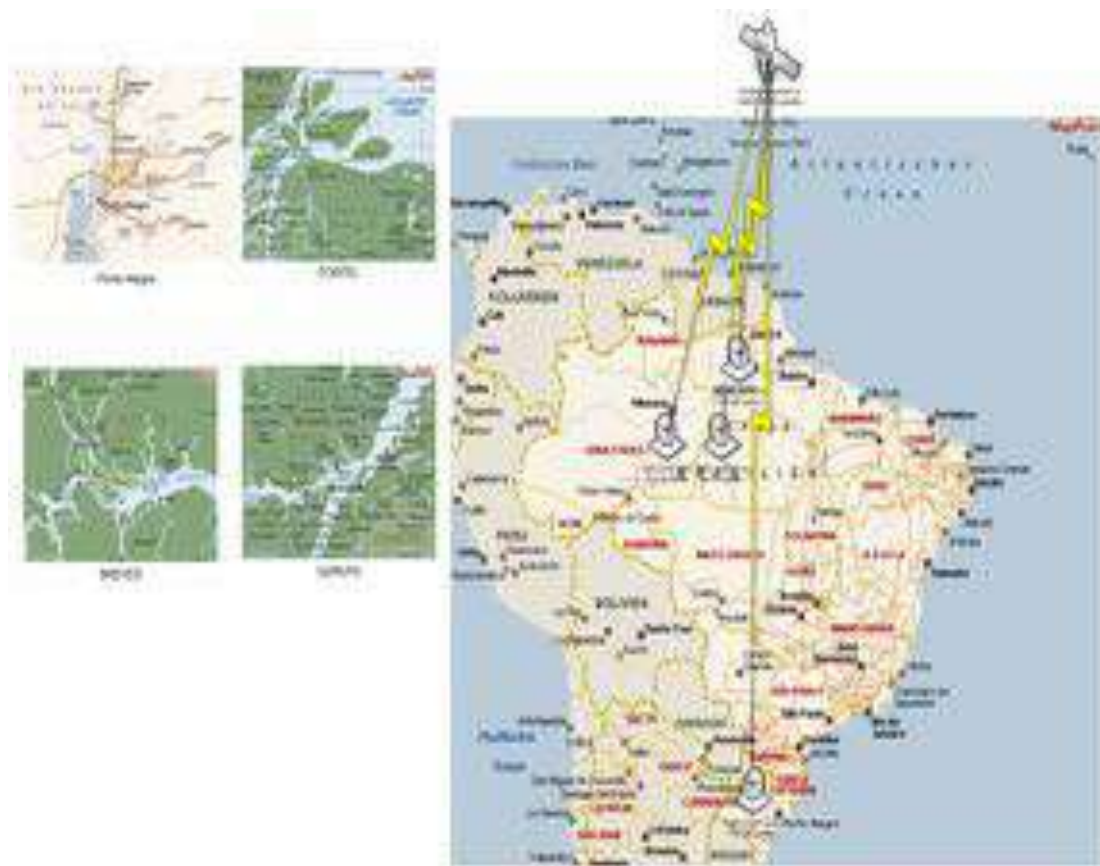


Figure 5.53: Geographical topology schema of the medical network

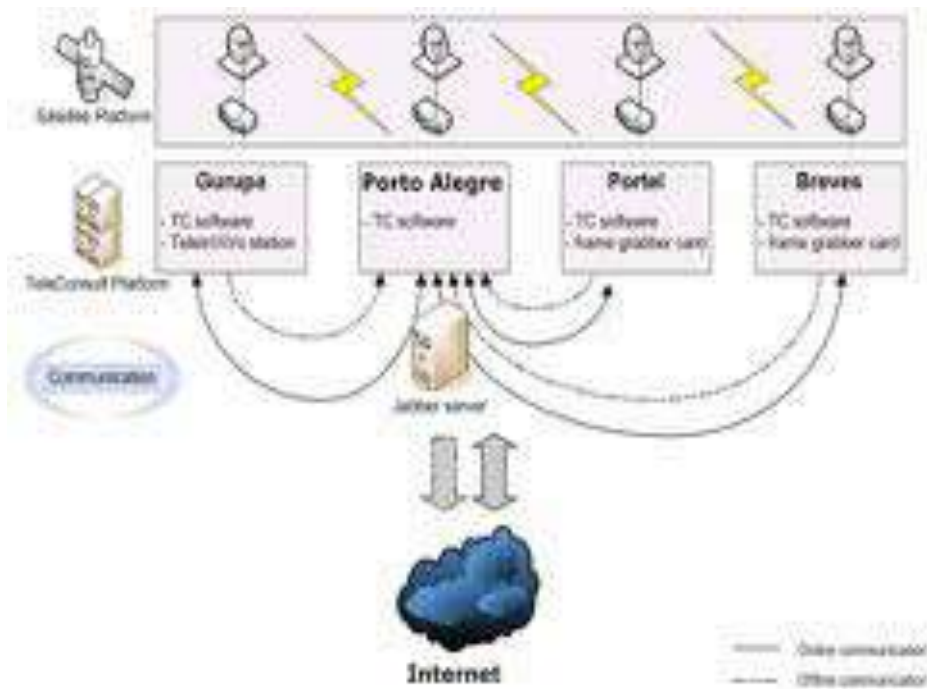


Figure 5.54: T@HIS system architecture

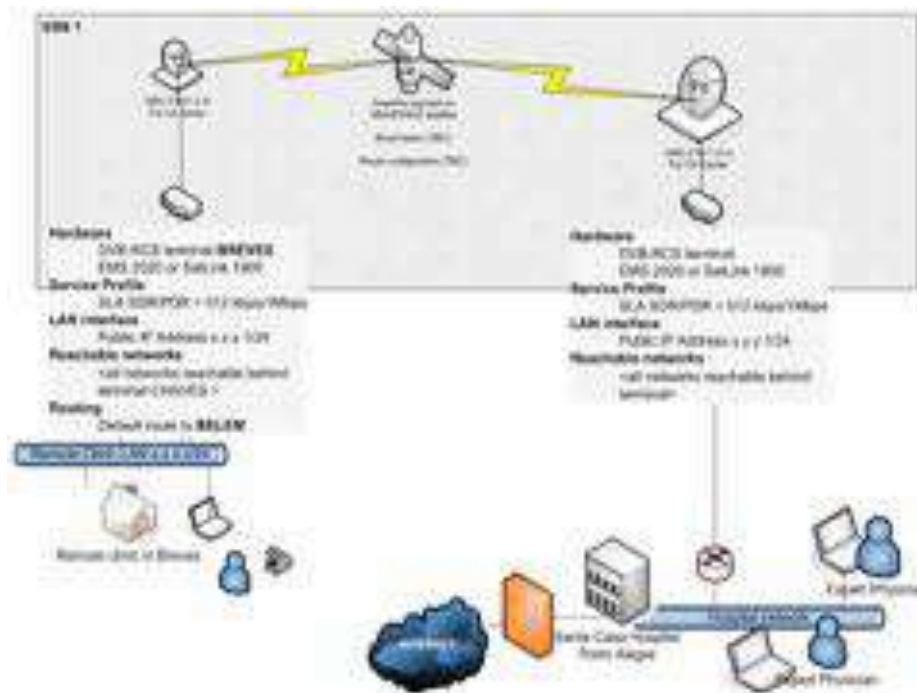


Figure 5.55: Porto Alegre-Breves deployment

After the end of the in-situ tests (Figure 5.55), between Braves (remote clinic) and Porto Alegre (referral hospital), we will continue with the deployments to the rest of the cities. At the same time the medical trials will start between Braves and Porto Alegre hospitals and a workshop will be held to show the health platform to the physician (experts and non-experts). Completing the deployment, two more satellite terminals will be deployed to remote clinics in Portel and Gurupa cities, respectively. A portable ultrasound will go through the region of the cities Gurupa and Afuá and will have the satellite base installed in Gurupa and will be connected to Santa Casa hospital located at Porto Alegre, Brazil.

5.3.6 Results

For the duration of 1 month the twenty (20) tele-consultations on ultrasound examinations performed between Santa Casa hospital in Porto Alegre and Breves hospital in Para states (Figure 5.56). The outcomes of the evaluations reports of the 20 tele-consultations show that the physicians performed six (6) on-line teleconsultations and fourteen (14) off-line teleconsultations (Figure 5.57).

In Table 5.9 the types and the number of medical examinations is depicted. The average medical data transferred from one site to the referral hospital was about 102.54 KB per teleconsultations. The physicians exchanged only a few ultrasound frames, where the diagnosis was unclear. The average time of the teleconsultations were about 10 min, according to the expert physician. Figure 5.58 illustrates the percentage of each type of ultrasound examinations performed.



Figure 5.56: During tele-consultation between Breves and Porto Alegre hospital

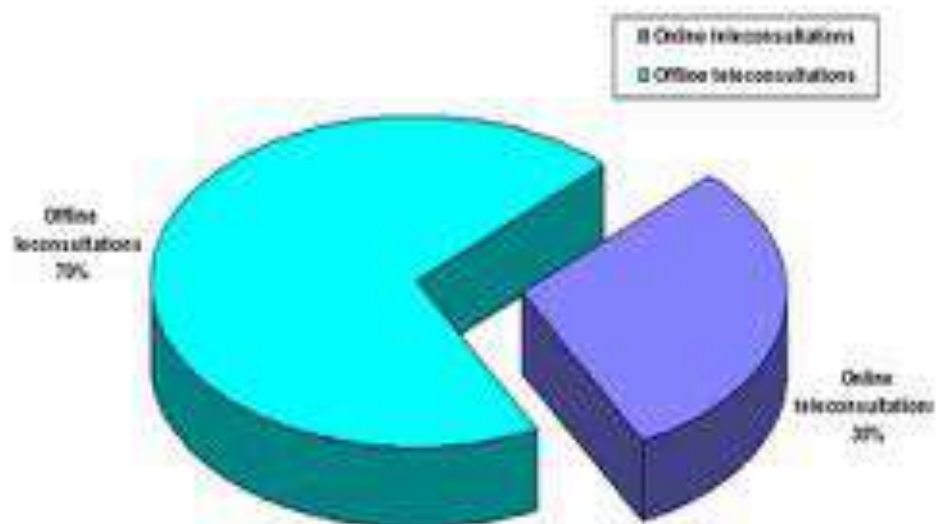


Figure 5.57: Online vs. offline teleconsultations

Type of examination	Area	Number of teleconsultations
Ultrasound	Abdominal	3
	Obstetrical	9
	Urological	4
	Gynecological	4

Table 5.9: Type and number of ultrasound examinations



Figure 5.58: Type ultrasound examinations performed by the remote physician and a tele-consultation took place

5.3.7 Conclusions

T@HIS offers a health telematics platform for cooperative work and transfer of medical data via satellite (DVB-RCS) communication channels. The technology allows the transmission and analysis of 2-dimensional (2D) and especially 3D medical images as well as video conference functionality between physicians. By this, T@HIS improves the exchange of medical reports, second opinions and treatment options within the physician-to-physician communication. The platform is created to be used in the field of the ultrasound examinations. However, it can be also adapted to the specifics of all other segments of the medical imaging (CT, MRI, PET).

T@HIS platform offers different applications:

- Second Opinion: for online or offline collaboration concerning suspicious patient cases
- Remote Reporting: for sending of imaging reports, that can be reviewed by remote physicians either in real time or later, using the system's store-and-forward capabilities
- Interdisciplinary Communication: for virtual meetings among doctors from various specializations

Our experience resulting from T@HIS project was that telemedicine application is very difficult to operate in very poor regions without changing the medical infrastructure and daily medical procedures. In more details the following aspects have to be taken into consideration:

- The need for telemedicine in the remote sites in Amazon in northern Brazil is urgent. However, due to the lack of non-permanent medical staff (staff change all the time, e.g. 4 to 6 months) facing difficulties to collaborate with IT applications, it is not trivial to have a telemedicine system in constant use.
- Contracted physicians working for hospitals in remote areas always have limited time for telemedicine applications.
- As the need for providers to transmit data increases, the need for higher speed and higher capacity telecommunications such as broadband becomes more important. The advantages of broadband for internet and voice-over-internet applications include the *always on* feature needed for store-and-forward applications. Higher capacity bandwidth is also important for accuracy and clarity in digital imaging applications such as tele-radiology, tele-dermatology and tele-pathology.
- A central question for telehealth providers is the availability of the broadband capacity of their locality. However, the high costs related to bandwidth utilization cannot be borne by the hospitals, alone. The delivery or access over satellite has to be seen as bundle of telecommunication services providing a stable communication highway for medical applications, as well as for cheap broadband internet offered to a city or VoIP to the citizens. In other words, the satellite bandwidth should be sold to a city or a company located to the remote sites, where it offers telecommunication services at a very low price.

Concluding, the more rural and less affluent the market segment or geographical area, the less likely the telehealth network will be sustainable without external assistance directed towards capital investment and operating expenses.

5.4 TENPET

TENPET (Trans European Network for Positron Emission Tomography) aims to evaluate the provision of integrated teleconsultation and intelligent computer supported cooperative work services for clinical positron emission tomography (PET) in Europe at its current stage, as it is a multi-centre project financially supported by the European Commission (Information Society, eTEN Program). It addresses technological challenges by linking PET Centres and developing supporting services that permit remote consultation between professionals in the field. The technological platform (CE-marked) is provided by MedCom GmbH, runs on Win2000/NT/XP systems and incorporates advanced techniques for image visualization, analysis and fusion, as well as for interactive communication and message handling for off-line communications. The Technical University of Madrid offers expertise on telecommunication issues.

Four PET Centres from Spain, France and Germany participated in the pilot system trials. The performance evaluation of the system is carried out via log files and user-filled questionnaires on the frequency of the teleconsultations, their duration and efficacy, quality of the images received, user satisfaction, as well as on privacy, ethical and security issues.



Figure 5.59: TENPET centers in Europe

TENPET promotes the co-operation and improved communication between PET practitioners that are miles away from their peers or on mobile units, offering options for second opinion and training and permitting physicians to remotely consult patient data if they are away from their centre. It is expected that TENPET will have a significant impact in the development of new skills by PET professionals and will support the establishment of peripheral PET units. To our knowledge, TENPET is the first telemedicine service specifically designed for oncological PET.

In the following sections will be presented both the technical innovations incorporated in the TENPET platform as well as the results from the first pilot studies at real and diverse clinical environments in the field of oncology.

5.4.1 Introduction

Positron emission tomography (PET) is a molecular imaging technique, with the potential to yield the physiologic information necessary for oncological diagnosis based on increased regional metabolism of radio labeled compounds and also to serve as a valuable tool for monitoring chemotherapeutic effects and the early diagnosis of tumour appearance and recurrence (Figure 5.60) for diagnosis as well as treatment planning and management of patients with cancer, apart from its contributions to medical and pharmacological research [112].

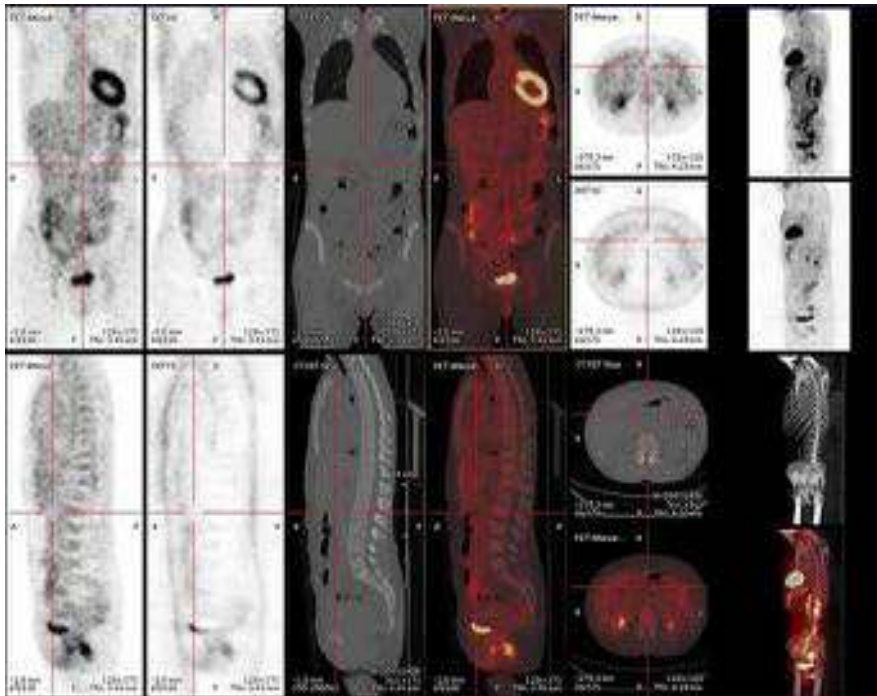


Figure 5.60: PET imaging

PET is able to locate in a quantitative way the regional distribution of specific compounds introduced in tracer quantities in the body of the patient, labeled with radioisotopes which decay emitting, among others, positrons. These particles annihilate with free electrons in the surrounding tissues producing a pair of gamma rays which travel in opposite directions at the speed of light. Current PET technology is able to detect both gammas generated, with extraordinary precision in terms of time of arrival of the rays to the detectors, with which the PET camera is equipped, and their energy. Based on this information, sophisticated processing and analysis of the information provided by all detected gamma ray pairs provides an accurate image on the distribution density of the tracer compound within the body which can in addition provide valuable quantitative information on the process of the uptake of the tracer by the various organs and tissues.

Traditional diagnostic techniques such as X-rays, computerized tomography (CT) scans (Figure 5.61) or magnetic resonance imaging (MRI) produce anatomical images of how the internal organs look like. The premise with these techniques is that there is a visible structural change in anatomy caused by disease. However, biochemical processes are also altered with disease and may occur before there is a change in gross anatomy. Furthermore, PET can provide medical doctors with important early information about very subtle changes of function in tissues, due to disease related modifications in tissue perfusion, cell metabolic rates, etc. This allows physicians to diagnose and treat these diseases earlier and consequently more efficiently and accurately, according to the axiom *the earlier the diagnosis, the better chance for treatment*.

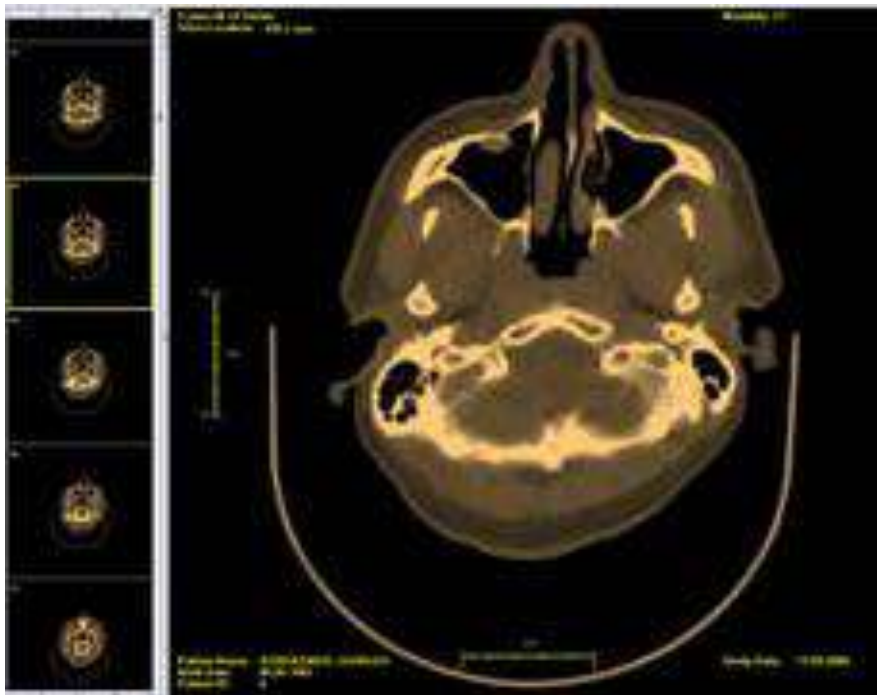


Figure 5.61: CT imaging

PET can also help physicians monitor a patient's response to treatment, as well as identify distant metastases that can affect treatment, helping curtail ineffective treatments and reduce unnecessary invasive procedures. The field of PET has been emerging today into clinical diagnostic medicine and is approved by many insurance carriers for coverage.

Although complementary to other medical imaging modalities (MRI, CT, etc) PET (Figure 5.62) is often installed in independent health care centres (known as PET Centres) or in separate units within the nuclear medicine departments of major hospitals. The somehow autonomous nature of a PET Centre is due to its extremely specialized and expensive instrumental equipment and maintenance, the requirements for a particular construction for its housing, its high demand for financial input and needs for highly qualified and trained multidisciplinary personnel.

PET requires highly qualified physicians and technicians and only few PET Centres operate in each European country (Figure 5.63), separated by language and cultural barriers. Furthermore, some Centres are specialised on particular cases whereas others count only little

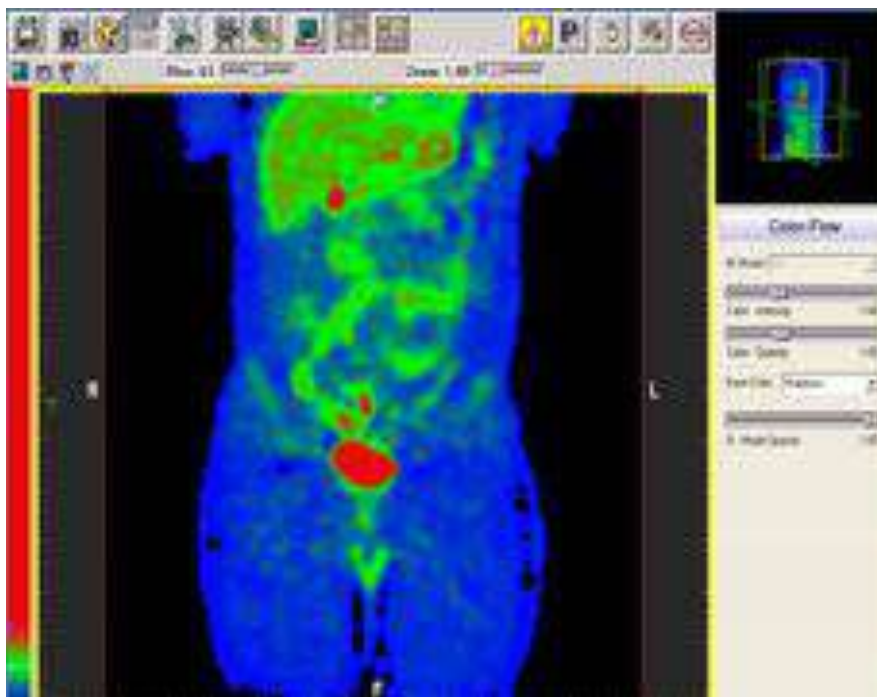


Figure 5.62: PET whole body scan

time of operation and consequently need support, training and advice from PET Centres with long-year experience.

TENPET comes to cover these needs, develop specific services for the technology implemented and set the first step towards the formation of a solid network covering most of the European PET sites. Moreover, the wider TENPET network includes some of the major referring centres (general hospitals, large health care centres, etc) to the PET Centres, with the aim of facilitating the process of patient referral and allowing the ordering physician to link and discuss directly with the examining physician the patient's images and results.

This project can be classified in what has been called tele-nuclear medicine by the Society of Nuclear Medicine, which has recently published a list of guidelines that outline the capabilities needed for a tele-nuclear medicine system [113].

Until now, the major need for such a service has been identified as the case of remote reporting, especially in emergency cases [114, 115]. Java applications have been reported on the implementation of a tele-nuclear medicine system a few years ago [116, 117, 118, 119], however activities in this field have rather been scarce until now.

Recently, a French group reported on the development of an electronic light-box called Positoscope [120], onto which PET studies can be downloaded, displayed, reported and sent to remote sites for expert advice. This device looks like a classical light-box equipped with a small touch-screen and a digital sound recorder. The system can be connected to local PET scanners and long distance high speed networks, with the primary purpose of transmitting difficult PET studies to remote experts for evaluation.

The TENPET project goes beyond the restricted principle of remote reporting, by allowing physicians to conduct a real-time integrated on-line session on a specific case. At the same



Figure 5.63: A typical positron emission tomography facility

time, it provides an advanced platform for image visualization, analysis and processing, as well a complete database system for data storage and autonomous operation within a clinic.

In addition, is the only system specifically available for PET that can link together the PET imaging center and the referring physicians in a simple to use platform, which runs on conventional PC platforms and operates in the plug-and-play principle without long installation or training phases.

5.4.2 Imaging collaboration application

The platform is composed of a number of single components that are working together. Each component can run as an independent process on the PC. The component executables will be found normally in the installation directory of TeleConsult (Imaging collaboration application) and its sub-directories. The components are:

- TeleConsult - Main Application, a combination out of DICOM Viewer, image grabbing software and medical telecommunication tool.
- DBClient (InViVoDB) - database client. Tool for the data access both locally and in connection with a database server.
- DBServer - Database server. Makes it possible to have one single data pool, available for example for a whole clinic with 1 to n TeleConsult workstations.
- TeleDamon - Telecommunication service, which is handling the exchange of messages with other TeleConsult workstations.

- Jabber communicator - An instant messaging tool for exchanging messages in real-time and store-and-forward mode among the registered users.
- StoreSCP - Implementation of the DICOM [121] store SCP service. Handles the receiving of files from modalities using the DICOM protocol for the sending of medical image data.
- StoreSCU (MC-storescu) - Implementation of the DICOM store SCU service. Handles the sending of files from TeleConsult to applications that support the DICOM file exchange.
- MCStarter - Starts the services TeleDamon, DBServer and StoreSCP, when booting a PC. In some cases these services are desired to run, even if no one is logged in to a workstation.
- MCTaskBarUpdate - When a user logs in this service informs the other services, that they can enter their icons in the windows task bar.
- Fusion module - is used to register and align two datasets originating from different modalities (e. g. CT and PET) or from the same modalities but acquired at different times (e. g. pre- and post CT scans).

In more details, TeleConsult application is the main application of the platform. It is a combination of a 2D and 3D DICOM viewer [122], an image grabbing software and a medical telecommunication tool. Figure 5.64 shows the user interface of TeleConsult. The largest part of the user interface is used for the display of the images. On the left side of the software all images, currently loaded into TeleConsult are listed. In the mid of the user interface, there is place for showing the details of one or more images. All operations a user of the software can operate, can be assigned to the following eight modules:

- The Database Interface menu
- The Image view menu
- The File I/O menu
- The Geometry menu
- The Greylevels/Colors menu
- The Tools menu
- The Cine menu
- The Teleconsultation menu

The Database client is the interface between TeleConsult and the database file, where patients, studies, images and messages are stored permanently (Figure 5.65). Over the same graphical user interface it is possible to access a database where the data is stored locally on the workstation or to access data which is held centrally on a database server.

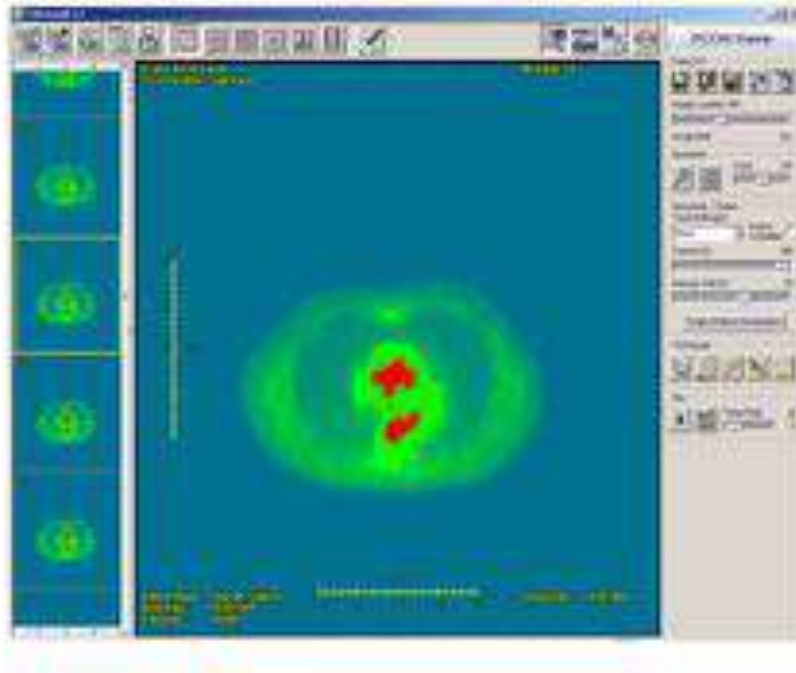


Figure 5.64: PET study in 2D DICOM viewer



Figure 5.65: Database client user interface

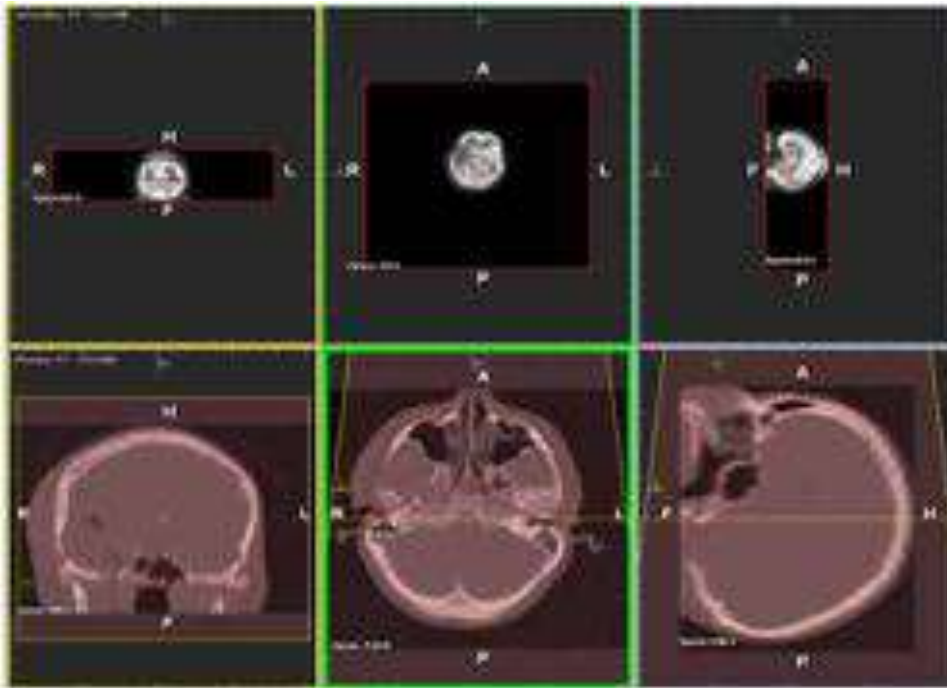


Figure 5.66: Fusion of a 3D PET data set and a CT scan

Image fusion and registration

The FUSION module is used to register and align two datasets originating from different modalities (e. g. CT and PET) [123] or from the same modalities but acquired at different times (e. g. pre and post CT scans) [124]. The result of a dataset fusion can be viewed in two different modes. Thereby one image data set is defined as the primary image set and another as a secondary image set. The image fusion module merges the primary image with the current secondary image set. Before the images are merged the positioning of the two image sets in relation to each other must be registered. There are several modes used for the registration procedure:

- Manual registration
- Marker based registration
- Automatic registration

During the manual registration the secondary volume can be shifted and rotated until the user thinks both volumes are matching. During the marker-based registration, landmarks are set on both volumes. A merging algorithm merges the volumes in recognition of the markers. The automatic registration uses an algorithm to compare both volumes and register them. After the use of each registration method, the volumes (3D image sets) are merged [125]. Figure 5.66 shows the fusion of a 3D PET data set and a CT scan.

Image compression

As we mentioned, the issue of the transmission of large data sets over the (usually low) bandwidth had to be solved. In addition to the possibility of offline-sending, for the online-sending a wavelet-based image compression algorithm [126, 127] has been implemented for the size reduction of the image data sets to be transmitted. The compression is lossy, but very efficient in cases where bandwidth is a crucial issue. Otherwise, a loss-less compression can be used for the data transmission. In addition the available image formats, e.g. DICOM have already the possibility to store images in a compressed format.

5.4.3 Communication aspects

Apart from the PET image visualization and the fusion with images from other modalities, the main target of TeleConsult is, to increase the quality of patient treatment and scientific work in the way of making the collaboration between two doctors or institutes easier. Thereby we focus on the sending of images, together with additional useful information from one place to another and on the discussion of these images online, whereby the discussion partners are sitting in different places.

Thereby we distinguish between on-line collaboration and off-line messaging. For the on-line collaboration it is necessary that both users are online at the same time, whereby off-line messaging does not require that the remote communication partner is available, when the messages are sent.

Both methods have its advantages and disadvantages. On-line sessions have more options for the interaction and exchange of information. Especially within TeleConsult the principle *what you see is what I see* (WYSIWIS), which means that both partners are having the same view at the images during the online-session, has great advantages. The main disadvantage is that both communication partners need to be available at the same time, which is on the other hand the main advantage of the offline-method.

The online communication between two workstations is implemented over TCP/IP based on virtual point-to-point (or point-to-server) connections. Figure 5.67 shows the usual workflow of a collaboration session. After both partners have connected, the first step is to exchange the images. This step is optional, because it is possible to send the images in advance by using the offline messaging functionality. Images are therefore only transmitted if they do not already exist in the database of the remote communication partner. During the step *Perform Online Consultation* every kind of manipulating the visualization of the images is possible.

In addition, the two doctors can communicate over chat and add additional graphical and textual annotations to the images, in order to render more precisely their conclusions. For the synchronisation of the two connected applications, only short commands are sent. This enables online consultations even over connections with a low bandwidth, using the principle of interface sharing.

Jabber is an instant messaging systems such as Skype, MSN, ICQ or AOL. Instant messaging system [128] are considered a convenient way of chatting. Nowadays, instant messaging is used for business to business communication [129, 130]. In the future, instant messaging system will get more ground and will be deployed in many applications such as medical

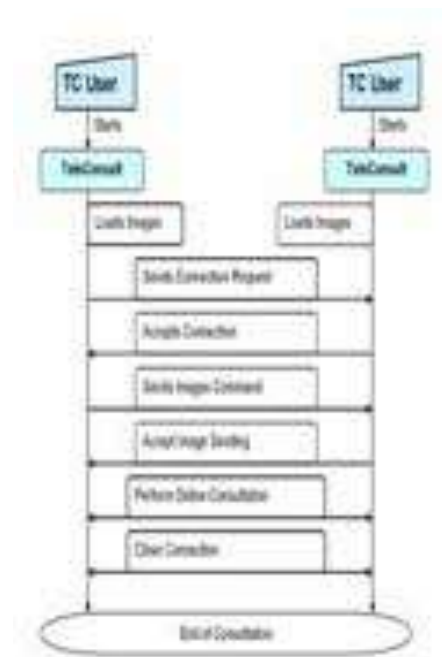


Figure 5.67: Workflow of an online teleconsultation

applications [131]. Within our project, we integrated an instant messaging system taking advantage of jabber protocol.

Jabber instant messaging system is different from other instant messaging systems since it is based on XML. In addition, jabber is an open source xml protocol, which makes jabber more distributed and easily accessible to everybody independent the platform.

A jabber instant messaging system consists of a hub server and many remote nodes, which are able to be connected to the server. The hub is responsible for keeping tracks of users' presence status and to forward the messages to the right user.

Jabber protocol [132] can be easily encapsulated into HTTP protocol [?, ?] and be forwarded through firewalls. A very common problem among medical applications is how two different remote applications could exchange information when they are located behind firewalls, which permit only outgoing traffic. We could tackle this problem if we place a server somewhere in the internet, which accepts incoming connections, as shown in Figure 5.68.

If the physician would like to communicate with, or send files to other physicians, s/he has to use the Jabber communicator as shown in Figure 5.69.

In addition, the jabber communicator offers a store-and-forward functionality. The users can send a message (still image, series of images, annotations, text, voice) to other users making use of the offline messages functionality, as illustrated in Figure 5.70.

Furthermore, the application provides adequate functionality for online and real-time collaboration among the physicians (Figure 5.71).

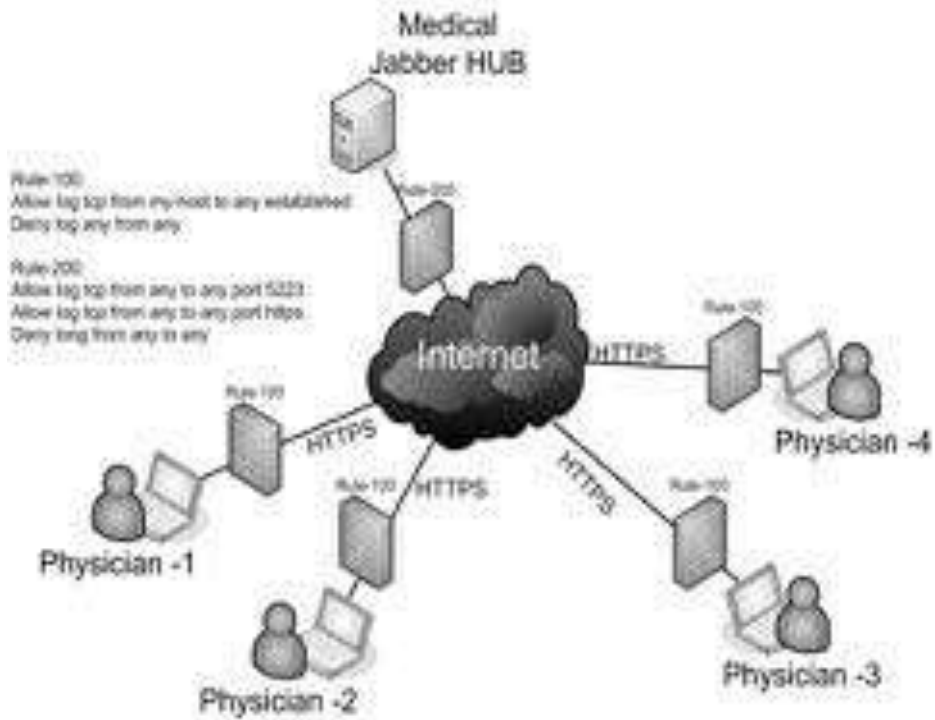


Figure 5.68: Jabber network



Figure 5.69: Jabber communicator for exchanging medical imaging information

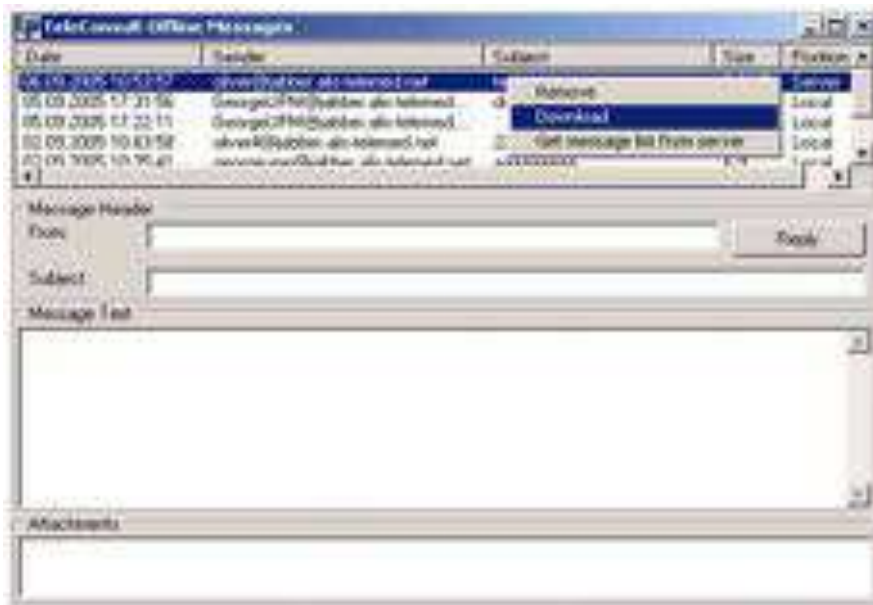


Figure 5.70: Accessing offline messages



Figure 5.71: Establishing real-time communication with another physician

5.4.4 Use cases

In this section we will describe several use cases for the operation of the platform at the trial sites.

Case 1: Online Consultation with online image exchange

The following events are part of this use case:

1. The patient is examined in a normal hospital. Medical images are made of the patient.
2. The doctors decide to contact the expert centre to clarify open questions concerning the clinical case together with an expert.
3. A date for the online consultation is made.
4. At the specified date the doctors clarify the open questions with the expert. During the online-consultation the images are exchanged.

Case 2: Offline Consultation with offline image exchange

The following events are part of this use case:

1. The patient is examined in a normal hospital. Images are acquired for the patient.
2. The doctors decide to contact an expert centre. Therefore an offline message together with the images of the patient is compiled.
3. The message is sent to the expert centre.
4. In the expert centre, an expert reads the message and investigates its content.
5. The expert creates comments on the images and answers the message together with its comments.

Case 3: Patient is sent to the expert centre. Images are sent offline

The following events are part of this use case:

1. A patient is investigated in the hospital. Medical images are made of the patient.
2. After the examination, it is decided that the patient needs to be sent to an expert center.
3. An offline message is compiled and sent to the expert center, in advance of his visit there.
4. The patient is sent physically to the expert center.
5. The patient is examined in the expert center. The images that are sent with the offline message are used for the diagnosis as well.
6. If necessary, additional images are made.

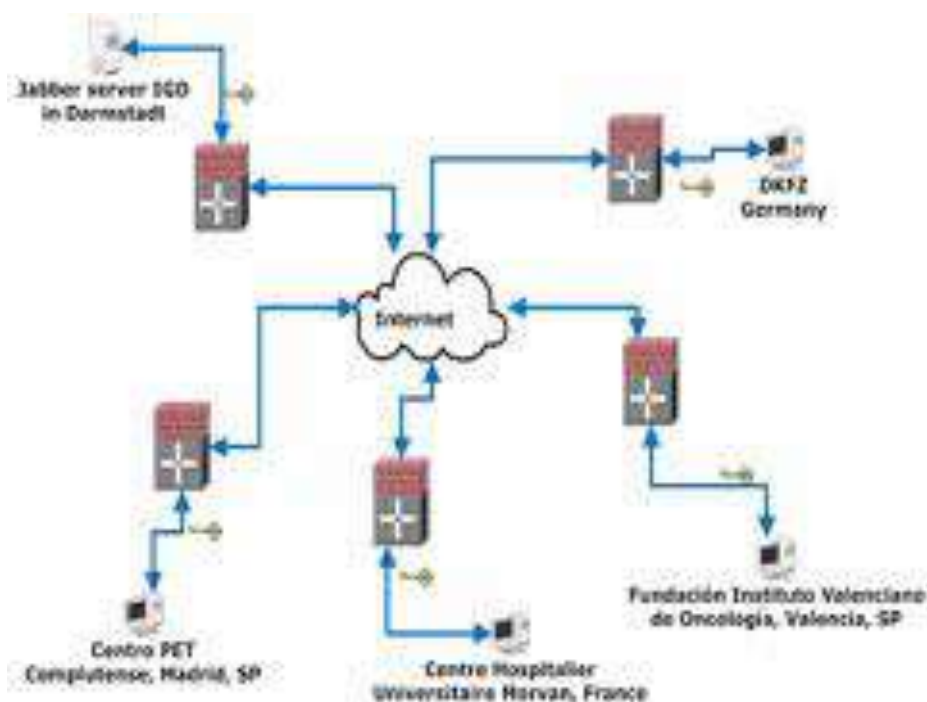


Figure 5.72: TENPET system topology and deployment

5.4.5 Deployment

The deployment of the system involved four PET Centres from Spain, France and Germany. In more details:

- Centro PET Complutense, Madrid, Spain (CPC)
- Centre Hospitalier Universitaire Morvan, Université de Brest Occidentale, Brest, France (UBO)
- Fundación Instituto Valenciano de Oncología, Valencia, Spain (FIVO)
- Deutsches Krebsforschungszentrum, Heidelberg, Germany (DKFZ)

All centres were able to communicate with each other over internet, as illustrated in figures 5.72 and 5.73

5.4.6 Results

Centro PET Complutense, Madrid, Spain (CPC)

The first scenario involving CPC and clinical trials of the TENPET platform was based on teleconsultations between the centre and FIVO, which was the second participating clinical pilot trials site in Spain (Figure 5.74). Based on this scenario a number of regular weekly sessions were held between the two centres.

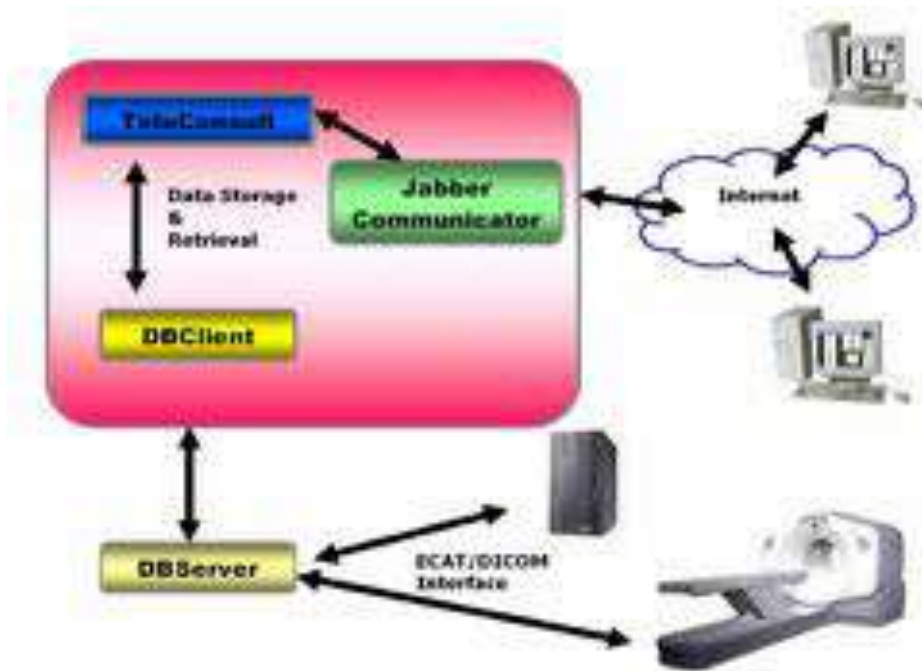


Figure 5.73: Interaction of TENPET software components

During these sessions a total of 31 teleconsultations were carried out between the two centres, 17 from CPC to FIVO and 14 from FIVO to CPC. Out of them, a total of 14 were online (1 from CPC to FIVO and 13 from FIVO to CPC) and 17 offline (16 from CPC to FIVO and 1 from FIVO to CPC).

The online teleconsultations were performed to cover urgent cases, while offline communications were used in all other cases. In all cases, the second opinion business case has been applied in these trials. The large majority of cases addressed during the 31 teleconsultations were PET whole body images (>93% of the cases), with the remaining involving patients with brain images only. An average of 9min per teleconsultation was devoted by the nuclear medicine physicians for image interpretation and analysis, with an average of 3.8min for the transmission of an average of 4.8Mb PET whole body images. No correlation was found between the time duration of the teleconsultation and the difficulty of the case reported.

Similar times were observed for the transmission of equivalent size CT images that were in 34% of the teleconsultations used for interpretation purposes through overlapping with the PET data facilitated by the TENPET platform. No correlation was found between the time necessary for the transfer of data and the size of the data transferred. The large majority (82%) of the cases examined were medium difficulty (score 3) and the use of the TENPET platform was found to have a high impact (score 1) in most of them (85%). Finally, the performance of the TENPET platform derived using the individual case study evaluation forms was summarised by a 100% scoring of 1 (excellent) on the easiness of use and the functionality of the displaying modules, which were particularly appreciated with the concurrent presence of the transmitted CT images.

In February 2005 (month 10 of the project's duration) significant changes have taken place



Figure 5.74: Dr. Miguel A. Pozo, during a teleconsultation session with FIVO at the TENPET workstation

in the medical team at CPC with the leave of the chief medical doctor of the Centre. At that time, the TENPET[†] platform was proven very useful for the training of the new medical personnel that entered CPC during 2005. It can be stated that the TENPET platform has been evaluated in nearly real conditions, regarding basically the second opinion business case, within CPC during the second half of the project.

In summer 2005 CPC signed an agreement with PET Cartuja, a PET facility in Seville, Spain, for the supervision of all diagnostic reports produced at CPC during the rest of that year. Due to the problems in the installation of the VPN connection at PET Cartuja, the communication between CPC and PET Cartuja started by using Web applications (plain e-mail for the transmission of sample slice PET images and diagnostic reports, www.yousendit.com, etc.). However, the introduction of the jabber communicator in the latest versions of the TENPET platform permitted the installation of the system in Seville and since November 2005 a total of 198 patient cases have been transmitted to the medical doctors at PET Cartuja for second opinion.

From these teleconsultations, 28 cases (15% of the total studies) have been randomly selected for evaluation in the framework of the TENPET project (by completing the individual evaluation forms).

The purpose of these cases has been mixed, involving cases where simply information was passed (32% of the cases) while in their majority (68%) were held to aid the diagnostic confidence of the reporting physician at CPC. All of the teleconsultations involved whole-body PET-only studies. An average of 6.2Mb of data was transferred with an average transmission time of 1.6min per case and an average teleconsultation time of 7.7min. No correlation was found between the time necessary for the transfer of data and the size of the

data transferred. Considering the difficulty of the cases 16% of them were evaluated as presenting high difficulty (score 1), 37% as medium (score 2) and the remaining cases as easy (score 3). No correlation was found between the time duration of the teleconsultation and the difficulty of the case reported. In terms of the impact of these teleconsultations, once more not considering the cases that were simply used for information transfer, 26% were scored high (score 1), 26% were scored medium (score 2) and 48% were scored indifferent (score 3). In terms of the performance of the TENPET platform, considering both the categories of easiness of use and functionality of image display in the individual teleconsultation evaluation forms, the scores were good (score 2) throughout the cases considered by the reporting physicians. It is foreseen that this collaboration between the two centres will continue beyond the duration of the TENPET project.

In addition, Centro PET Complutense reached an agreement with Dr. Rodolfo Nuñez from the MD Anderson Cancer Centre in Houston, TX, USA, who undertook the responsibility to support the newly hired medical team in Madrid with especially difficult cases. During this period, 13 patient cases have been transmitted from Madrid using the TENPET platform to Houston and the evaluation forms for 7 of these studies have been completed (with random selection) and are also available at the secured section of the project's website.

These 7 teleconsultations were carried out covering high difficulty (score of 1) cases where the expertise of the external collaborating physician was deemed essential. As a result the impact of using the TENPET platform for the teleconsultation on these cases was consistently scored 1 (high impact) by the reporting physician. All of them were online, comprising of whole body PET datasets, an average data transfer time of 4.1min (for an average of 4.9Mb of data transferred) and an average teleconsultation time of 4.6min. No correlation was found between the time necessary for the transfer of data and the size of the data transferred. Equally no correlation was found between the time duration of the teleconsultation and the difficulty of the case reported. In terms of the performance of the TENPET platform, considering both the categories of easiness of use and functionality of image display in the individual teleconsultation evaluation forms, a high score (2: good) was consistently given by the reporting physician.

In summary, a total of 66 teleconsultations were evaluated between CPC and 2 centres in Spain and one in the USA, covering a number of mostly difficult whole body PET cases requiring a second opinion. The use of the TENPET platform carried as a result a significant diagnostic impact. Considering the data from all the teleconsultations an average of 3.2min per case was past in the transfer of an average of 5.3Mb of data. The transfer times were consistently higher for the 7 telecommunications with the USA. Finally there was no correlation between the time of teleconsultation with the TENPET platform and the difficulty of the case evaluated for any of the centre pairs that were considered with CPC. This is not surprising considering the large difference in the experience of nuclear medicine physicians in the different centres included in the study, which although difficult to assess in a practical sense should be the dominant factor in the teleconsultation time / case. On the other hand, the evaluation on the use of the TENPET platform in terms of easiness of use and functionality of the display modules has received high scores (between excellent and good, scores between 1 and 2), independently of the nuclear medicine physician using the platform.

The Centro PET Complutense has identified in the TENPET solution a powerful tool for the Centre to provide higher quality services to its clients. These are principally patient referral



Figure 5.75: Dr. Catherine Cheze-Le Rest during a patient PET scan

centres from the autonomous communities of Madrid, Castilla-La Mancha, etc., which refer patients to CPC for PET studies. Whereas until now the PET reports are sent to the referring hospitals by courier and in print or in CD-ROMs, now CPC intends to eliminate the delays and costs that these courier services represent by replacing the transmissions of reports and data (patient images) with TENPET-based offline message transmissions.

The first such pilot trial for the evaluation of the electronic fax business model for patient referral was established with the regional hospital of the Alcazar de San Juan in the autonomous community of Castilla-La Mancha. In Fall 2005, a concrete plan was developed, in order to install the TENPET platform (Jabber TC version) at that hospital. It was however realized that the Hospital implements a complex informatics security system, with firewalls which do not allow outgoing sockets on port 5222 via HTTP requests. MedCom and Fraunhofer IGD was informed about this situation and realized that the Jabber TC platform needed some further adaptations (implementation of an HTTP polling proxy login).

Centre Hospitalier Universitaire Morvan, Université de Brest Occidentale, Brest, France (UBO)

During the period of the commencement of the trials the PET scanner in Centre Hospitalier Universitaire (CHU) Morvan, Brest was upgraded to a PET/CT system. This installation took place throughout September 2005 and caused additional issues associated with the ability of the TENPET platform to read the exported image format as far as the CT images is concerned, which was not that originally considered. These issues were resolved by MedCom and Fraunhofer IGD in October and clinical trials with data from the new PET/CT system took place between November 2005 and January 2006.

Following the first scenario, data was transferred to the laptop of the physician at her home through the TENPET platform installed in the PET/CT acquisition room. The physician subsequently reported on the PET/CT images submitting her report that was sent back to the nuclear medicine department. An ISDN connection in the home of the physician was used during the transfer. A total of 34 patient studies were included in the trials and all teleconsultations were offline.

All of the cases included in the trials involved PET whole body images, with incorporation of whole body CT images in 65% of the cases evaluated. An average of 10min per consultation was devoted by the nuclear medicine physician. The time devoted on teleconsultations included the recording of the clinical report. Transfer of data was on average 3.1 minutes, with the variation in time depending on the number of bed positions used in each whole body investigation. In the cases where CT datasets were also used the overall data transfer time increased on average by 3.8 minutes.

All of the cases included in these trials were assessed as representing a medium difficulty (score 3), while the use of the TENPET platform was deemed as having a high impact (score 1) in the sense that the nuclear medicine physician was capable of assessing the images and delivering their report in a location away from the hospital environment. In terms of functionality and easiness of use for the displaying modules of the TENPET platform, a score of 2 (i.e. good) was given for all of the teleconsultation sessions.

In the second scenario associated with the use of the TENPET platform for the communication of datasets between the Nuclear Medicine department and the radiotherapy, originally some only CT images were transferred. However, the evaluation forms were only filled in all cases involving PET/CT fused images. A total of 40 such patient datasets were transferred. The communication was performed within the hospital network. A transfer time of 2.5 minutes was reported on average. In this specific scenario the use of the TENPET platform was to facilitate a first visual evaluation on the differences between functional and anatomical tumour volumes of interest. Only a total of 12% of the cases were considered of high difficulty (score 1), while the rest of them were considered as of medium difficulty (score 2). In the category of impact of teleconsultation all of these cases were assigned a score of 4 corresponding to information transfer only since the teleconsultation facility was not utilised as such. In the case of the efficiency of the displaying modules for the particular task a score of 3 (good) was given in all of the cases examined.

Finally, in the scenario of the use of the TENPET platform for visual presentation of PET scans in a multi-disciplinary meeting environment (interdisciplinary communication business case), a total of 24 cases were evaluated. Data was transferred from the PET scanner console to the laptop of the nuclear medicine physician through a local network port. The evaluation forms were filled by the nuclear medicine physician presenting the clinical cases. These trials were all performed prior to October 2005 (before the operation of the new PET/CT scanner) and therefore included PET whole body images only. 90% of the cases were characterised as difficult, since these were the one's chosen by the nuclear medicine physician to be presented using the TENPET platform, considering that their presentation on the TENPET display platform will permit a better comprehension of the cases than a simple hard copy output which is the alternative. The evaluation on the functionality and the easiness of use for the TENPET platform displaying modules was judged as good (score 3) in all of the cases examined.

In conclusion, the trials in the CHU of Brest concentrated on local deployment scenarios

for the use of the TENPET platform. The most significant in terms of the potential of the TENPET platform was that associated with facilitating the remote reporting for a Nuclear Medicine physician away from her department. Although the particular physician was reporting from her home the same scenario could apply in the case of a mobile PET unit. In the vast majority of such existing mobile PET units, examinations are carried out and reporting is issued from a physician located remotely in their departmental environment. In this case the TENPET platform was used with success scoring high on the easiness of use and the functionality of its displaying modules as well as on its impact factor since it was thought of as an extremely useful tool in that particular scenario. Finally, the two other trials carried out by the CHU Brest mostly covered the use of the platform as a PACS system in the case of combined PET/CT images as well as PET images only. It is true that although the tasks performed with the TENPET platform during these last trials could have been equally performed by a PACS station (if there was an existing system in place) the displaying modules of the TENPET platform are adapted to PET and CT images, something that is never the case with PACS systems, particularly in the case of PET or multimodality images requiring fusion displaying modules

Fundación Instituto Valenciano de Oncología, Valencia, Spain (FIVO)

Based on the trials plan, FIVO has held a number of weekly sessions with CPC. A total of 31 teleconsultations were carried out between the two centres, 17 from CPC to FIVO and 14 from FIVO to CPC. Out of them a total of 14 were online (1 from CPC to FIVO and 13 from FIVO to CPC) and 17 offline (16 from CPC to FIVO and 1 from FIVO to CPC). The on-line teleconsultations were performed to cover urgent cases, while offline communications were used in all other cases. The large majority of cases addressed during the 31 teleconsultations were PET whole body images (>93% of the cases), with the remaining involving patients with brain images only. An average of 9min per teleconsultation was devoted by the nuclear medicine physicians for image interpretation and analysis, with an average of 3.8min for the transmission of an average of 4.8Mb PET whole body images. No correlation was found between the time duration of the teleconsultation and the difficulty of the case reported. Similar times were observed for the transmission of equivalent size CT images that were in 34% of the teleconsultations used for interpretation purposes through overlapping with the PET data facilitated by the TENPET platform. No correlation was found between the time necessary for the transfer of data and the size of the data transferred. The large majority (82%) of the cases examined were medium difficulty (score 3) and the use of the TENPET platform was found to have a high impact (score 1) in most of them (85%). Finally the performance of the TENPET platform derived using the individual case study evaluation forms was summarised by a 100% scoring of 1 (excellent) on the easiness of use and the functionality of the displaying modules, which were particularly appreciated with the concurrent presence of the transmitted CT images.

Deutsches Krebsforschungszentrum, Heidelberg, Germany (DKFZ)

At the German Cancer Research Centre in Heidelberg, all PET studies are performed within the framework of the various research projects of the organization. The majority of the TENPET trials therefore at DKFZ were focused on the use of the platform to support these

research projects, emphasizing on the integration of software for the evaluation of PET images to medical diagnostics and therapy management in oncology patients.

This fact has been found that significantly differentiates the use and necessity of the application of the TENPET system and related services from the case of PET Centres focused on the performance of PET examinations for clinical routine and, as is the case of private companies such as the Centro PET Complutense or the PET Unit at Fundación IVO, in the framework of their basic business model.

TENPET trials at DKFZ have been, therefore, exploratory for the use of the platform in research environments, and for the scientific data and information exchange. Trials with a partner group at the Technical University of Warszawa, Poland, were performed successfully. The external partner was a software developer for PMOD, a platform for kinetic analysis of dynamic PET studies, among other functionalities.

Another set of trials was scheduled with a clinical team from the University of Athens, Greece. However, the attempt to coordinate the installation of the platform and its use did not work due to difficulties in the installation of the software versions by the local physicians in Greece and the lack of support by the technical personnel.

The DKFZ team had scheduled to perform teleconsultations with the PET Unit at the University of Haifa, Israel. However, they faced several technical and non-technical problems. Originally, it was planned that a person from Haifa would visit the DKFZ and gain experience with the software. However, due a delay with a grant the guest visit was delayed for Spring 2006, therefore these trials were not possible to be organized within the duration of the system trials.

Multiple national connections were made, mainly between Heidelberg and Fürth, Germany. All trials were always successful and the remote reporting application mode from the TENPET business cases was evaluated in this case. It was possible to provide the appropriate ports for the connections due to access to the firewalls. These trials demonstrated that even large data files (e.g. dynamic PET data) could be transferred using a 6.5 Mbits/s line without major problems. In addition, successful connections were performed between the DKFZ and MedCom using all software versions.

The remote reporting case has been also tested in international connections, between UPM and DKFZ: UPM transmitted to the DKFZ experts large data sets from dynamic PET studies performed at the Centro PET Complutense and they received back from DKFZ a detailed analysis of the data transmitted with valuable information on the proper performance and evaluation of dynamic PET studies

Therefore, in conclusion, regarding the evaluation on the reliability of the TENPET platform, the majority of the users thought that the system was repeatedly performing the tasks as required and that either little or normal levels of training were necessary in order to allow clinical users with good experience on computer and information systems to reach an acceptable level of operating the TENPET software. One of things that need to be definitely addressed in a follow-up release is, as suggested by half of the users involved in the clinical trials, the presence of error messages in wrong inputs.

Finally, the users of the clinical trials strongly agreed (57%), agreed (29%) or somehow agreed (14%) that the TENPET platform represents an efficient communication channel between colleagues, and that the services provided were at least equal (29%) or better

(71%) than previously employed practices. As a result in their large majority (86%) they thought that the use of offline consultations with TENPET should be used for diagnosis and that the authorities should empower the use of the TENPET platform (100% of the users)

5.4.7 Conclusions

The expected users of the TENPET services are PET Centres, regional health centres, large and small hospitals and clinics, with or without nuclear medicine services, mobile PET units and the referring physicians. In the course of this project, the market validation of the TENPET platform, customers of the TENPET services are considered all health units and professionals related with PET imaging.

The TeleConsult platform, which implements the TENPET services, eliminates this hassle and offers to PET specialists a concrete tool and specific methodology to contact other colleagues and request their cooperation in an efficient, easy-to-use and standardised procedure. Furthermore, both ends can exchange chat messages, send files (like medical reports, etc.) to each other, point regions of interest to the other partner with the telepointer, etc.

The major service categories for which there is a significant market margin for further development and business opportunity for the TENPET platform and services have been identified as the following ones:

- **Second opinion:** In this case a PET centre which is either new or is lacking experience will send the data to the more advanced centre for a second review. The problems herewith are diverse. Second opinion in other centres is not a paid service by European Union law. This can be practicable only for areas where private liquidation is possible. This could be implemented mostly in Southern Europe. Different protocols require different evaluation and thus a study replication. The doctors feel uncomfortable in asking for advice by another doctor who is considered to be an expert.

Concluding this, second opinion seems to be rather problematic. Possibly there could be a much better opportunity overseas. However, even in Europe this can be regarded as being a potential market especially for new-established PET centres asking for a limited period of time the assistance and support of the partner centre. In fact, this has happened in the past in several occasions and continues to happen now that many new PET sites open every year outside main capitals of the European countries. Even the Centro PET Complutense, coordinator of the TENPET initiative, at its early stage of operation in the mid 1990's had a support agreement with the University of California - Los Angeles (UCLA) for second opinion support on difficult cases.

- **Remote reporting:** Remote reporting is linked to the previous case. It can be also however extended to the case of mobile PET, where systems are mounted on trucks and are shared among peripheral hospitals. These peripheral hospitals perform the examinations of the patients in situ and send the data to the central expertise unit (Centre of Excellence) for evaluation. In addition to this, one PET scanner can be used as shared facility by several user groups, as it is a common case in France. Again, the data acquisition is taking place in one location and the evaluations of the data are performed in different sites.

In the remote reporting case, physicians have to report PET studies for which they feel they have a limited experience in some cases. By requesting remote expert advice, they get trained at the same time. At one point in time, they may feel well trained and request less expertise or the expert may judge the burden of performing expertise too time consuming. In either case, the number of requests will decrease and the need for a TENPET will be questionable.

Another way to consider the future of the remote reporting feature would be to decide that data acquisition for complex imaging studies need not be performed at the same location as reporting depending where expertise is located. TENPET would then become a very user-friendly teleradiology device. Up to now teleradiology has been essentially considered for providing remote areas with high quality medical services. In the case of PET, teleradiology can be extended to situations where a radiologist or a nuclear medicine physician can perform the acquisition and the reporting of standard cases but can request the help of a remote expert when needed. One can even consider a network of radiologists or nuclear medicine physicians, each of them specialized in rare or complex imaging studies. In the latter case, acquisition of such studies could be performed all over the network while reporting would be performed by one or two members of the network. Such a network would also be a solution for ensuring that complex studies can be always reported, provided that experts of a given study are somewhere available at the time of the request.

- **Interdisciplinary communication:** In this case, doctors from various specializations (diagnosis, surgery, radio-oncology) have to meet together to discuss the case regarding the patient treatment. Such a discussion takes place in a physical room with all experts sitting in front of a whiteboard, light-box, etc. A potential application of telemedicine could be to be used as a tool for virtual meetings among such specialists. In such a case, the technology should be extended by a video-conferencing and a speaker phone over internet capability.

The TENPET platform can be also used as a display of selected images of a given patient during multidisciplinary staff meetings. In this case, images are selected from various modalities and displayed on the monitor such that they can be seen by a large audience, and that the relationship between the various images can be understood easily by the audience.

- **Electronic fax:** Here the system is used as a transportation medium for transferring the results of hospital back to the referring position. Currently this is done by courier services and films, however this practice is becoming more and more difficult because the data are today, practically all of them, in digital form. Electronic fax to referring positions can be a practicable solution only if the installation and the users is as simple as possible, but the location of the referring physician. Referring physicians are not willing to invest time and efforts in using a complicated system, anything more complicated than a fax is already too complicated.
- **Advanced visualization console:** Apart from the telemedical features integrated in the system, the TENPET platform could be a value at itself if it is offering features not available to the commercial scanners. Today the evaluation software accompanying the system is rather rudimentary and is not offering a lot of reviewing possibilities. However, this console is given *for free* as a gift to the doctor purchasing the PET

scanner. In order for this doctor to invest money on a different technology, the investment must be moderate and must offer significant benefits as compared to the software available to him today. Advanced fusion changing of colour look-up-tables, segmentation and multislicing capabilities could be regarded as being such possibilities.

Through the provision of a bundle of services via an easy-to-use user interface, TENPET offers, as it has been also seen in the above reference scenario, numerous benefits:

- Allows the speedy, accurate and filmless communication between referring physicians and specialized medical personnel at a PET Centre.
- Allows PET physicians to easily access to the radiology data (CT, MRI, etc.) of the patient in digital form, ready to be registered and fused with the PET images for the final diagnosis. Until now, the common practice is that PET reports are compiled based on CT or MRI films that come with the patient's records, viewed on the classic light-box.
- Allows the exchange of experience between physicians and medical personnel from PET Centres with distinct specialisations, for diagnostic, training or scientific purposes.
- Brings all PET Centres in Europe (and beyond) closer, breaking barriers of frontiers, language or culture and nurtures the vision of many towards the foundation of the European PET Association.
- Brings together advanced medical imaging technology and health telematics networks applications to a platform that can be directly applied to the whole spectrum of teleradiology, thus increasing by orders of magnitude the market size of the developed services.

Within the broader context of TENPET, all countries are experiencing increasing demand for health care services and therefore, by implication, technology-driven diagnostic and screening programs and alternative methods of health care delivery are featuring in current policies and practices. Due to the increasing necessity and importance of health care in the community, there is a need for novel state-of-the-art systems and services that are compact, portable, interoperable and competitively priced. Health care industry professionals are considered to have an important part to play in the development of products and services in the environment of changing social and economic conditions. These can be considered to be the following:

- To be able to influence the development of new approaches to health care delivery and impact on the advancement of clinical practice.
- To contribute to the broadening of European health care industry influence and image, through implementation of practical solutions.
- Create an environment for successful expansion into new business segments.
- Outline product concepts that could be developed to satisfy the potential demand for remote care systems.

Furthermore, TENPET fosters and promotes the development of new target applications in the teleconsultation, networking infrastructures and architectures including the integration of fixed, mobile, on-line and off-line technologies and their application to advanced health telematics networks. The TENPET service is based on proven technology, taking into account recent advances in medical image technology, ubiquitous communication and intelligent interfaces, and is based on innovative systems, user-friendliness, cost effectiveness and quality of service.

Chapter 6

Conclusion and Future work

In this chapter, I am going to summarize the conclusions of the dissertation and provide trends for future work on the subject.

In health care domain, communications play an important role. The clinical information of the patient should flow continuously and in an integrated form among groups and institutions. Due to the limitation of resources, human and material, it is necessary to have a better utilization, on one hand lowering the costs and on other keeping or increasing the quality of the health care service provided to the citizens. Both developments and implementations of new telematic services have been increased with the technological developments in telecommunications and informatics. Telemedicine can give the necessary information regardless of the location of the patient or the health care provider, particularly in developing countries. This enables a better utilization of the medical resources [133, 134].

The presented medical imaging collaboration platform provides medical doctors with all necessary tools for communicating and exchange medical information over different communication media such internet, ADSL, and conventional phone lines. Our application provides a wide spread of possibilities to enrich a given image material with additional information and to send it as a message.

That can happen in off-line mode or in on-line mode. Moreover, the on-line mode gives the opportunity to communicate over long distances with a given partner in real time. In this case, both doctors observe the same image data set and through text messages and transferred mouse actions to the remote PC, they can discuss interactively over a medical case.

Our medical imaging application is able to communicate and exchange medical digital images over any communication medium that offers a TCP/IP layer such as internet, ADSL, ISDN, GSM, WLAN or even satellites, as it has been shown in chapter 5.3. Additionally, the application is able to convey any digital data, such as audio, images, videos and text. For the presentation of the medical imaging data a 2D and 3D DICOM viewer were implemented (Figure 6.1).

The Jabber protocol and server architecture are developed around the concept of exchanging XML document content between multiple locations. Jabber is an XML message switch,

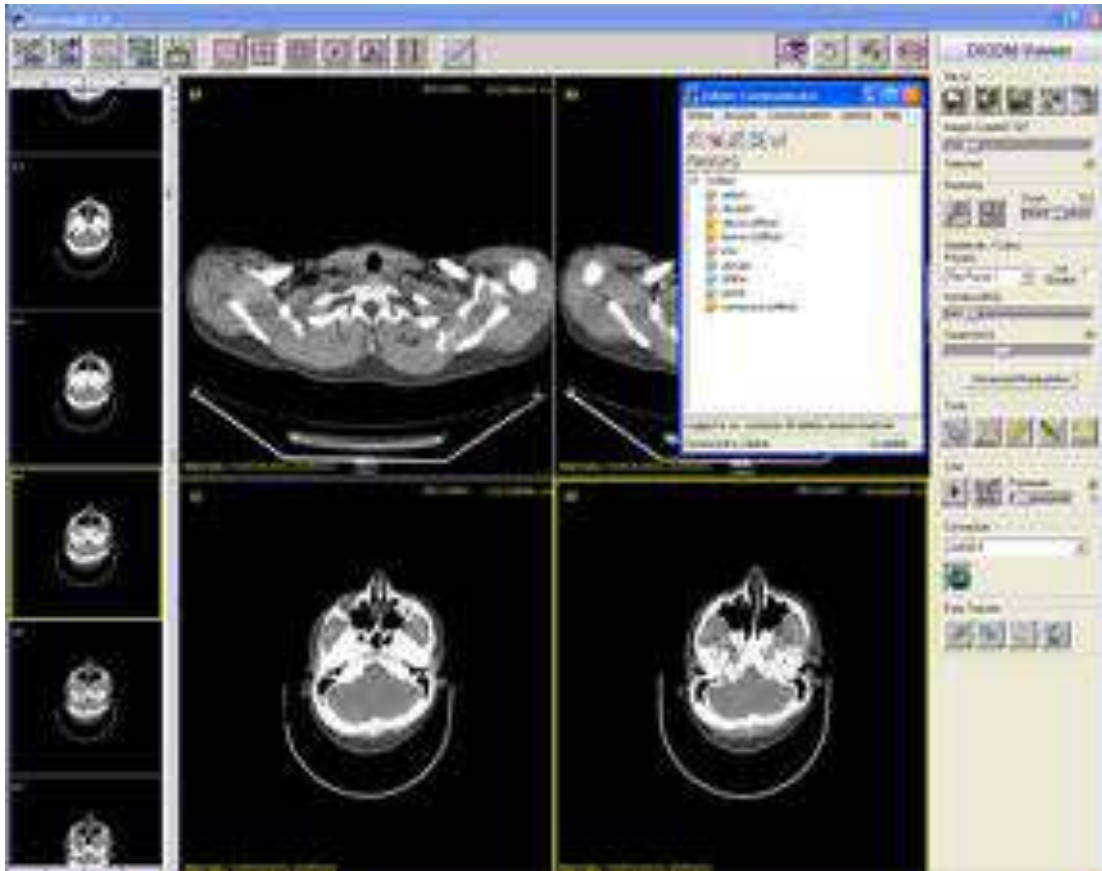


Figure 6.1: Medical Imaging collaboration application with Jabber communicator

supporting both external clients and internal or external services. Jabber does primarily provide an instant messaging service. However due to simplicity and extensibility of the Jabber protocol, it is very simple to deliver new services built around Jabber. Examples include creation of voice recognition services, connectors to the cellular SMS network, archiving servers, and buddy agents that perform database queries using natural language commands.

Jabber's Extensible Instant Messaging advantages come from the following architectural features, to name only a few of them:

- Presence: Information on each user's availability is a key component of Jabber IM. Presence [128] is the information concerning a contact's willingness to receive information and the state of their system.
- Open Protocol: Jabber XMPP (XML based Messaging and Presence Protocol) is accessible. The completely open protocols enable developers to extend the APIs
- XML compliant: Elaborating messages are delivered as XML fragments. The applicability and portability of the XML to other applications made Jabber an obvious choice for creating IM extensions.
- Secure Socket Layer: Open source Jabber server and client support SSL connection,

thus Jabber users are able to exchange data without worrying about data security and compromising.

Throughout this dissertation, I introduced a new method of communication among physicians, based on Instant Messaging (IM). Our medical imaging collaboration application has been adapted to IM communication, introducing an IM server, based on jabber protocol. Applying IM to our medical application, I needed to shift the communication layer from point-to-point to centralized peer-to-server schema, as illustrated in Figures 6.2 and 6.3.

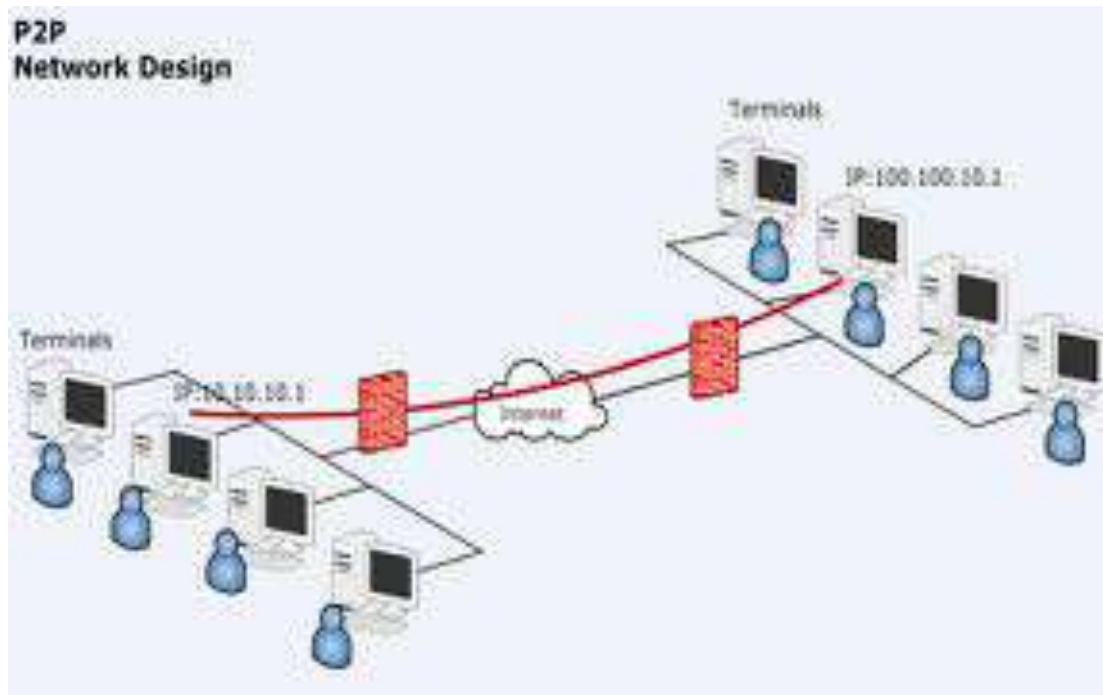


Figure 6.2: Point-to-point communication

Firewalls have heavily been deployed on the Internet, preventing inbound traffic from reaching protected resources. Most peer-to-peer services, whether in data centres or personal computers, will be in firewall protected environments. In typical hospital firewall configurations, only sessions initiated outbound can be established, as a result to protect the resources inside the firewall. Once an outbound request has been made, an inbound response is then allowed to the same socket and address. This displays a major problem for service accessibility, especially services depending on peer-to-peer connections. Jabber acts as a broker to create logical peer-to-peer connections to a known, fixed entity. This fixed entity is the Jabber server (Figure 6.4). It acts as a destination for outbound connections, with the Jabber network [9] providing a central terminating point for establishing two-way connections.

Due to the issues identified above (firewalls, dynamic locations, and discovery requirements) users will not be able to link together in direct peer-to-peer connections. They will rather establish logical peer-to-peer connections, using some central intermediary to direct the traffic, which enables doctors to be reached anywhere on the network. The central Jabber server provides message switching and connectivity, but the perceived relationship by the clients is a direct peer-to-peer connection [130, 135]. In heavy limited networks,

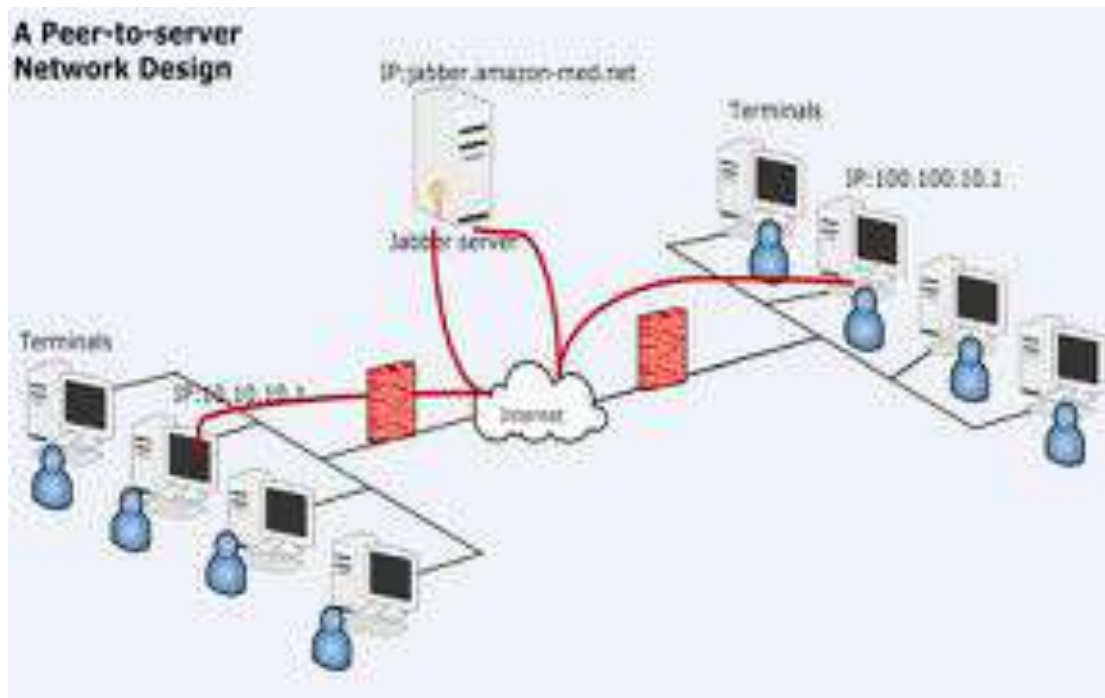


Figure 6.3: A Peer-to-server communication for IM schema

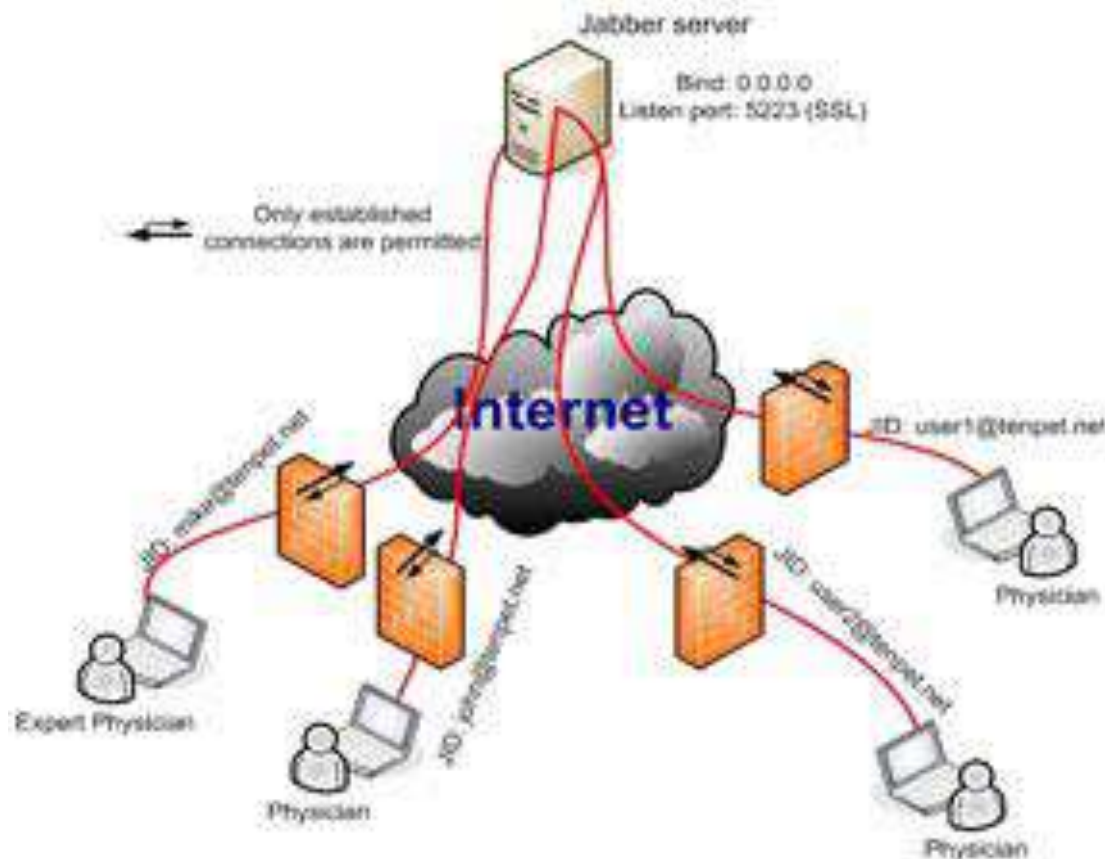


Figure 6.4: Medical Imaging collaboration application over Jabber network

	P2P deployment	Jabber deployment
Presence and Availability	no	yes
User mobility	no	yes
Security through firewalls	yes	yes
Binary data overheads	no	yes
XML compliant and routing	no	yes
Transportation over HTTPS	no	yes
Configuration effort	yes	no
Logical peer-to-peer connection	no	yes
Point-to-point connection	yes	yes
Directory and discovery services	yes	yes

Table 6.1: Comparing P2P vs. Jabber communication methods

e.g. hospital networks, physicians are still able to connect to Jabber network, making use of the build-in *HTTP-polling* functionality of our medical imaging application, as shown in section A.3.6.

Comparing P2P vs. Jabber communication methods, we can highlight numerous advantages offered by Jabber protocol. First of all, the presence status and directory services offered by Jabber core protocol are a plus. In addition, Jabber is able to be routed over HTTPS protocol by encapsulation of XML messages. One of its disadvantages is the base64 encoding used for binary data transmission. In other words, the data need to transfer over Jabber is 33.33% more than over a point-to-point binary socket transmission. In base64, triplets of 8-bit octets are encoded as groups of 4 characters, each representing 6 bits of the source 24 bits [136]. In the table 6.1, I summarize the advantages and disadvantages of each configuration for data and image transmission of our imaging tele-medical application.

In my dissertation, I proposed a new algorithm for estimating medication adherence trends of long-term ill patients, living alone. Applying the proposed algorithm to medical adherence systems, physicians are able to make an assessment in a very short time. Applying this novel algorithm for assessment to a very large databases of patient, I can predict patient behavior and assess medication adherence in a very short and automated way.

Future work

Instant messaging can be easily deployed into medical environment and it could be easily adapted into doctors' every work. Particularly, Jabber protocol that is an open source and open specification protocol. It could be used to connect firewall protected services and users. Furthermore, the directory services and presence status offered by the protocol make it very attractive to medical applications that need to have real-time and store-and-forward communication. In addition, further work should be put on the extension of the jabber protocol to support real-time voice over IP, and elaboration of real-time protocols for medical applications and particularly for medical imaging application, where large amount of data need to be transferred.

Additionally, IM messaging could be seamlessly deployed in home-care application, for communication between patients at home and physicians or hospital doctors.

Furthermore, medical equipment could make use of the jabber protocol for their communication with central databases and medical repositories.

Moreover, if technological advances in the areas of sensing, computation and wireless communications continue at their current rates, we could develop small medical devices with built-in features of medical analysis and communication. This is an interesting area of future research, as it brings together many different fields and has the potential to help billions of people.

Concluding, I need to highlight that future research should focus on the development of health communication protocols over IP, integrating medical communication protocols and devices in a seamless way and proving automated methods of analysis of medical input data.

Appendix A

DICOM

A.1 Medical imaging standards

DICOM Standard

In this chapter we will an overview of the implementation background of DICOM standard. Additionally, important implementation of the DICOM functionalities will be presented.

DICOM background

From 1970, computer tomography (CT) and 1975 Magnetic Resonant tomography (MR) have been adapted by a large number of hospitals and the use of medical imaging in medical diagnosis has been stronger. In addition, in radiology process and routine very large data images often in analog films is stored, though the increase powerful computers give the option all those data digitally to store and archive. The use of the computer for the medical diagnostic created needs immediately after the new technology and new methods of image analysis, and presentation as well as the communication among various image modalities and image archiving systems, came up.

One of the problems occurred by the large number of manufactures of imaging devices and the different imaging processing systems. Each imaging device, in DICOM format, stores the imaging data as well as information about the imaging device, in order later on those data to be able to be interpreted in a common way. Transferring images from an archiving system to an application of image analysis and presentation, and moreover, which of the data from many different modalities could be interpreted, imaging standards started to show up.

In 1983, American College of Radiology (ACR) and National Electrical Manufactures Association (NEMA) established a committee for the design and development of an international standard for imaging data archiving [137]. In 1985 the first version of ACM-NEMA was immediately adapted and accepted by the manufactures. This first version gave to the manufacturers a lot of space to define their own specific data into the protocol. In

1988 a second version came up and in 1992, DICOM 3.0 version, based on object oriented approach, showed up.

Today, DICOM 3.0 is the most well defined standard in medical imaging processing. DICOM (Digital Image Communications in Medicine) allows archiving of different medical and imaging modalities on different computer systems, in a standardized way, as well as supplementary data information on images and patients. Despite that, DICOM data can be extended under defined rules. DICOM format is being developed every day and often new data information modules enrich the standard. All the new updates and amendments of DICOM standard are announced on the internet from where they are developed and additional implementation information can be acquired.

The problem was that by 1988 many users wanted an interface between imaging devices and a network. While this could be accomplished with Version 2.0, the standard lacked the parts necessary for robust network communication. For example, one could send a device a message that contained header information and an image, but one would not necessarily know what the device would do with the data. Since ACR-NEMA Version 2.0 was not designed to connect equipment directly to a network, solving these problems meant major changes to the standard. The committee had very early adopted the idea that future versions of the ACR-NEMA Standard would retain compatibility with the earlier versions, and this placed some constraints on WG VI.

In a decision of major importance for the standard, it was decided that developing an interface for network support would require more than just adding patches to Version 2.0. The entire design process had to be re-engineered, and the method adopted was that of object-oriented design.

In addition, a thorough examination of the types of services needed to communicate over different networks showed that defining a basic service would allow the top layer of the communications process (the application layer) to talk to a number of different network protocols [23]. These protocols are modeled as a series of layers, often referred to as *stacks*. The existing Version 2.0 stack that defined a point-to-point connection was one. Two others were chosen based on popularity and future expansion:

- the Transmission Control Protocol/Internet Protocol (TCP/IP) and
- the International Standards Organization Open Systems Interconnection (ISO-OSI).

Figure A.1 shows a diagram of the communication model developed. The basic design philosophy was that a given medical imaging application (which is outside of the scope of the standard) could communicate over any of the stacks to another device that used the same stack. With adherence to the standard, it would be possible to switch the communications stacks without having to rewrite the computer programs of the application.

After three years of work, WG VI, with many valuable suggestions from industry and academia, completed ACR-NEMA DICOM (also called DICOM 3.0). It is a much larger standard than Versions 1.0 or 2.0, but it also supports many more features than either of the prior versions.

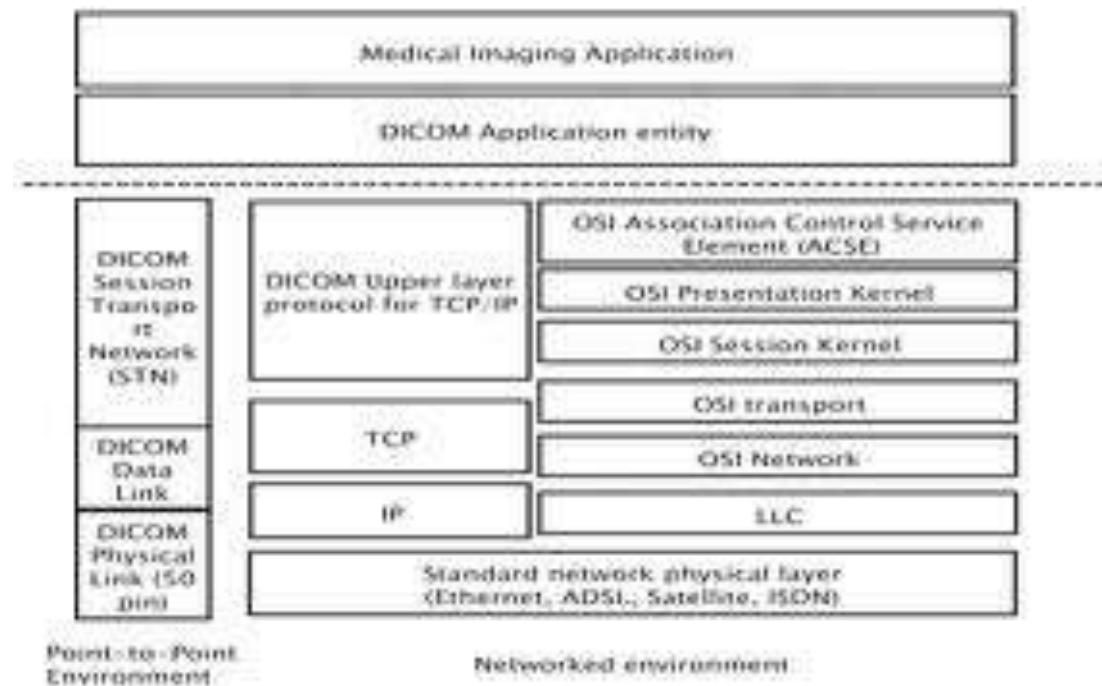


Figure A.1: DICOM layers

Structure of DICOM format

The data in the DICOM standard can be adapted for various tasks. For instance, it can be used in a communication application of a radiology information system (RIS) or for archiving purposes. Furthermore, it can be used for medical diagnosis since both vital medical information and medical image information are stored in the format. For instance, despite the image information data, also audio data or diagrams could be stored and conveyed.

Information Object Definitions

For two applications to share a common view of the information to be exchanged, DICOM uses an object-oriented abstract data model to specify information about real-world objects. This model collects information about related objects into what is called Information Object Definitions (IODs). An example of real-world objects that might form an IOD is a patient together with a study of the patient and a CR image of the patient. Each of these realworld objects are represented by an Information Entity within in the IOD. It consists of attributes that describes the properties of an object, for example the patient's name, patient id, sex etc, [138, 139]. The structure of an image IOD can be seen in Figure A.2. It is important to point out that an IOD does not represent instances of a real-world objects, but describes a class of objects and how instances of such classes should be represented and interpreted during information exchange.

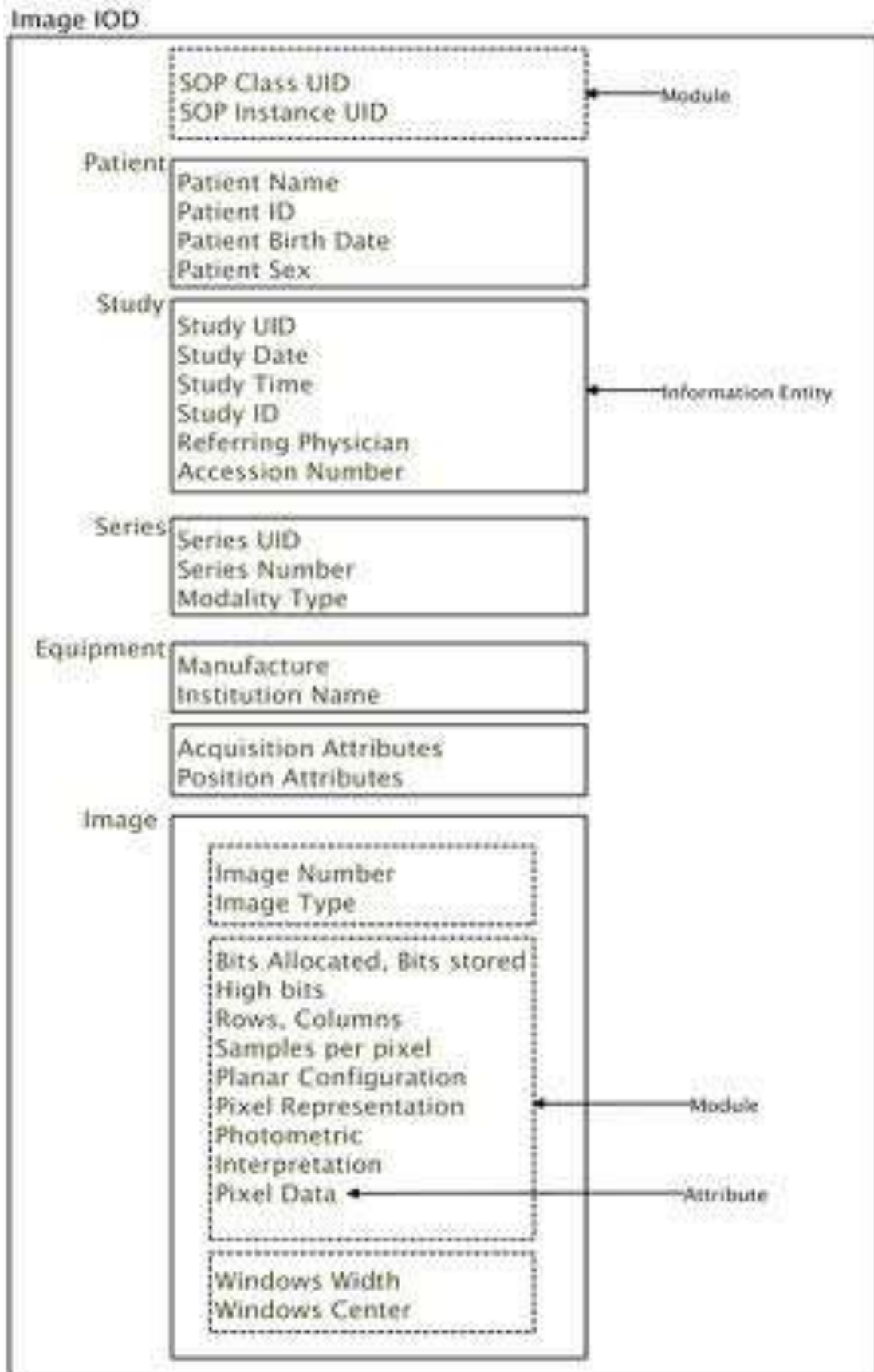


Figure A.2: An example of a composite image IOD

Group	Attribute	Tag
Patient group	Patient's name	<0010,0010>
	Patient's Size	<0010,1020>
	Military rank	<0010,1080>
Acquisition group	Intervention Drug Dose	<0018,0028>
	Therapy description	<0018,0039>
	Filter material	<0018,7050>

Table A.1: Groups and Attributes in DICOM

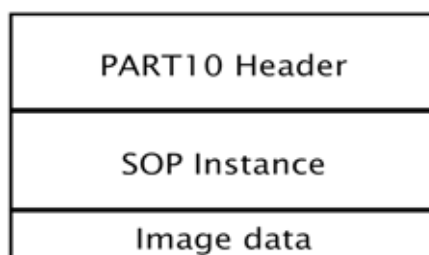


Figure A.3: Data component of image archiving

Data structure - Attributes

In DICOM standard the data is organized in object oriented approach [140]. The data has been defined as attributes in classes. Therefore, DICOM Header as well as instances of information objects is stored as attribute values. In DICOM standard ca. 1500 different attributes are defined. Depending on the medical application, some of them could be option or mandatory.

Each attribute unique defined within a *Tag*. Each *Tag* is stored as 32 bit value, which is composed of two 16 bit figures. The two sixteen bit figures define the so called Group and Entry, in following form:

$$\langle Group, Entry \rangle$$

The attributes are sorted into groups and the entries are sorted into each group, as shown in Table A.1.

Main parts of image archiving data

Figure A.3 depicts the three parts, that compose image archiving data.

DICOM header

In chapter 10 of the DICOM Standards [141], it is defined as the so-called PART10 Header. The PART10 encapsulated all the definition for going through the rest of the data and

Attribute name	Tag	Description
Preamble	none	Application's profile. Most of the case is empty.
DICOM Prefix	none	"DICM" string for data type identification
Group length	0002,0000	The length of the Header in bytes
Meta info	0002,0001	2 bytes long. Each bit represents a version
Media Store SOP Class UID	0002,0002	UID of the SOP class
Transfer syntax	0002,0010	UID for "Little endian" or JPEG baseline
Implementation Class UID	0002,0012	UID of the originator
Implementation Version Name	0002,0013	Version of the originator/file creator
Source application	0002,0016	Application's title of the originator
Private Information UID	0002,0100	UID of the originator - private information
Private Informaiton	0002,0102	Private information

Table A.2: Composition of a DICOM header

interpreting manufacture encoded information. Beyond that, declarations of the composer of the DICOM file are given. In old versions of the DICOM standard, data and information which do not belong to the archiving but to the processing of the system, are not stored into the DICOM header. This rule does not apply to preamble and DICOM prefixes in attributes/elements, as depicted in Table A.2. The information in DICOM header is not used for extracting imaging information and moreover is not necessary for the medical image visualization. An important role for the consequent data interpretation is played by the *Tag* < 0002, 0010 >, so-called *transfer syntax*.

SOP-Instances

All information, from the patient's information to the interpretation's information of the medical image, is organized into objects. Service Object Pairs (SOP) is able to apply any operation on the objects. For instance, they can store, transmit or even convert the objects.

In DICOM standard numeral Service Object Pairs (SOP) for particular tasks and assignments are available and they are defined into the so-called SOP-Class, in advance. For the visualization of the medical image data and the presentation of patient's information, the Image SOP-Class [139] is used. This Image SOP handles a number of predefined date with attributes, instead of general definitions.

The last attribute of the Image SOP Class is always the Pixel Data attribute. It indicates the

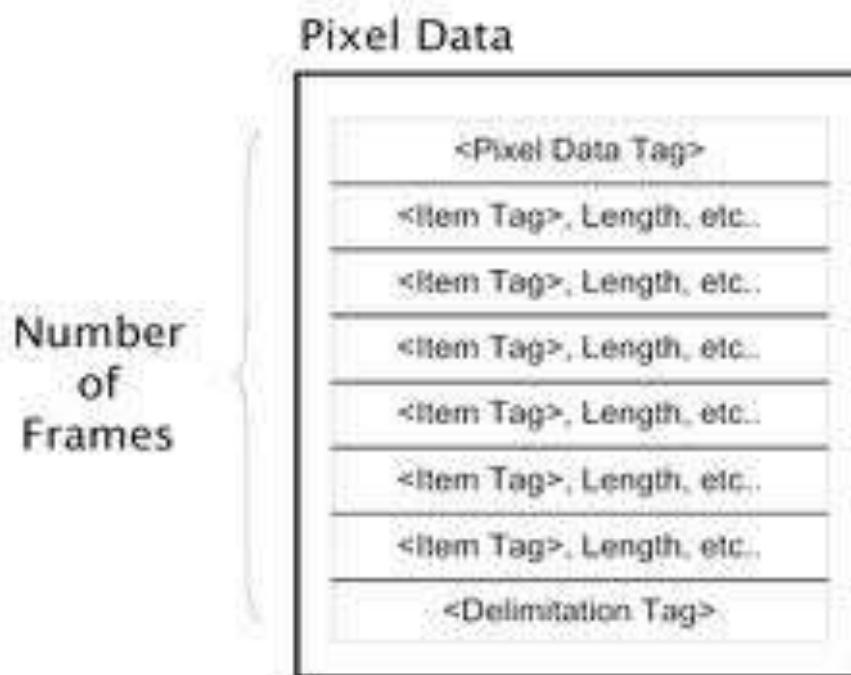


Figure A.4: Organization of the image data

data of one or more images, as shown in Figure A.2.

Imaging data

In DICOM format, the imaging data is the dominant element. Information on the images is stored in the Image SOP instance. Information on the image representation and interpretation can partly be found in Header and mainly in the attribute of Image SOP instance. The imaging data is stored in image segments. The end of the whole imaging data is indicated by the limitation tag (Figure A.4).

Coding of the attributes

A large part of the information, carried in DICOM format, is stored into the attributes. The values of the attributes can be stored in a various coding schemas. In the text below, we are going to explain.

As already it has been indicated, in previous paragraphs, in DICOM, the attributes are stored into sixteen (16) bits values. This tag is followed either by a data type or length of the attribute in bytes. The latter is called Length-Tag. In rule, it is a 32 bit unsigned long values. The exact format for the declaration of the attributes, is being indicated by the Transfersyntax attribute, which is defined in DICOM header. The Transfersyntax attribute could be implicit or explicit:

- Implicit means that the Length-Tag is following the *Tag*. In this case the data, in the DICOM is formed as follows:

Attribute name	Data type	Data type description
Patient name	PN	The name of the patient. A string max 64 bytes long. Sachpazidis Ilias
Patient ID	LO	A string 64 bytes long
Patient's birth date	DA	Date string in format "JJJMMDD"
Patient's birth time	FD	Floating point 64 bit, 754:1976
Patient's age	AS	A string 4 bytes long in format "nnnW", e.g. "120W" for 120 weeks

Table A.3: An example of data types

```
<Group,Entry>, Length n, Attribute value n bytes
```

Listing A.1: Implicit definition of attribute

- Explicit means that a data type follows the *Tag*, before the length is given. Independently of the data types of the attribute, the data formed as below:

```
<Group,Entry>, 2 bytes data type, 2 bytes length n ,attribute ←  
value n bytes...
```

Listing A.2: Explicit definition of attribute

If the length of a value is *FFFF* in hex then the length is undefined and the explicit syntax is used and the data format is displayed to below:

```
<Group,Entry>,Data type,length FFFF,Attribute value,<ending tag>
```

Listing A.3: Explicit definition of Transfers attribute

In this case the delimitation tag indicates the end of the attribute value.

Data types

In the DICOM standard there is one or more attributes as optional defined [142]. These are all enlisted in the so-called data dictionary of the standard, along with each attribute [143]. In the following table A.3 is shown an example of defined attribute and their data types.

In the data dictionary the tokens of each data type are given. A detailed description can be found in the section *Data structures and Encoding* in DICOM standards [144]. Due to huge number of data types defined in the DICOM, we are going not to depict them, here. However, we have to highlight that the data types can be distinguished into:

- **Simple data types**, which are strings followed by individual bytes
- **Complex data types**, which are for instance decimal number and the values is calculated with the help of following bytes.

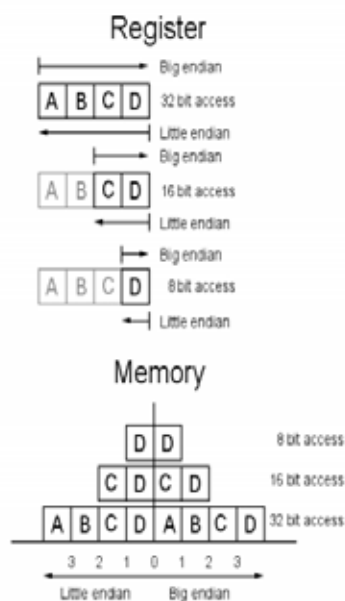


Figure A.5: Mapping registers to memory locations. An examples of storing the value 0x0A0B0C0D in memory

Bytes order

The way of interpreting the values and the specific coding used for storing the data is given by the Transfer syntax attribute in DICOM header. Little endian or big endian are the two types of bytes order (Figure A.5) and indicate the way of reading and interpretation of the attribute values:

- Little endian means that the low-order byte of the number is stored in memory at the lowest address, and the high-order byte at the highest address -*The little end comes first*-. Intel processors (those used in PC's) use *Little Endian* byte order.
- Big endian means that the high-order byte of the number is stored in memory at the lowest address, and the low-order byte at the highest address. -*The big end comes first*-. Motorola processors (those used in Mac's) use *Big Endian* byte order.

Pixel data coding

The pixel data can be stored as either signed or unsigned values. The pixel representation attribute defined in Image SOP-Instance provides that information. In case that we have a coloured pixels for instance RGB images, is indicated in planar configuration attribute, as well as the format of the values of different colour channels is indicated. The pixel data could be read either in a group of four RGB values or in a group of 3 channels and in channel the value of on colour is indicated as illustrated, below:

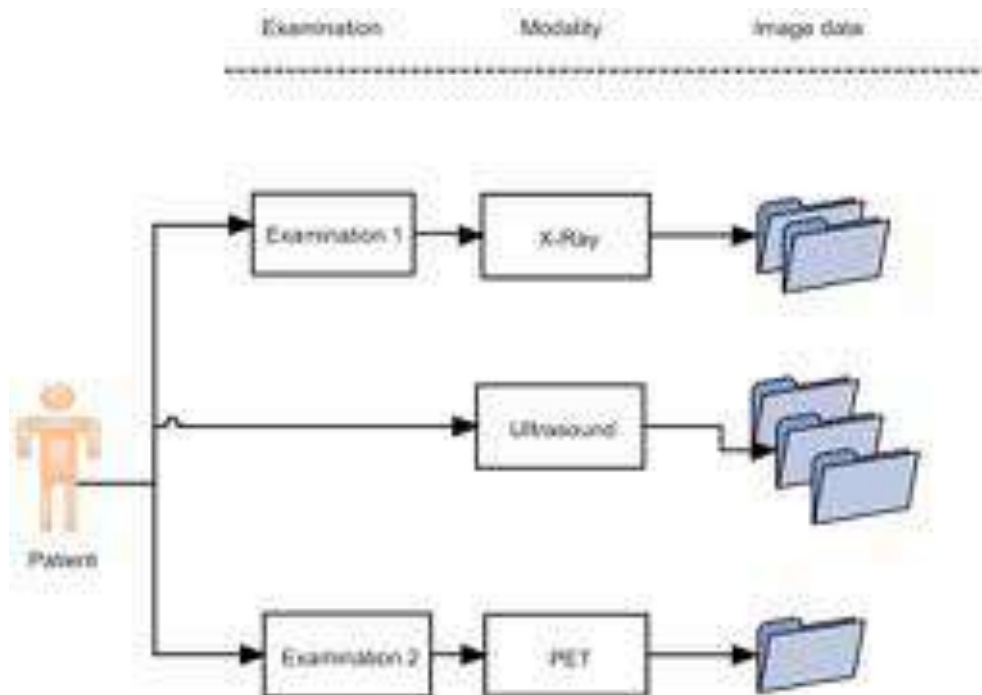


Figure A.6: Representation of the real world in DICOM

RGB, RGB, RGB, RGB

or

$R, R, R, R - G, G, G, G - B, B, B, B$

DICOM in real world

A medical examination and the related medical procedures can be represented in DICOM. Those medical procedures are conveyed by one or more DICOM data. Consequently, the medical examination results are grouped, together to form an meaningful classification of the data, as illustrated in Figure A.6. There are, however, many other classifications and groups of medical examination and theirs results, for instance, the hospital where the examination took place, the medical station or even the responsible medical doctor.

In the following paragraphs, I am going to give the requirements needed for the correct representation of the medical images. Further, I shall show how we could processing the image data sets.

A.2 Imaging representation

For the image presentation and viewing, a DICOM viewer was developed and enriched with new features. The DICOM standard was depicted, in details in chapter A.1. Now, for the both correct and best image representation, we need to apply to correct a colour model, geometrical model and transformation options.

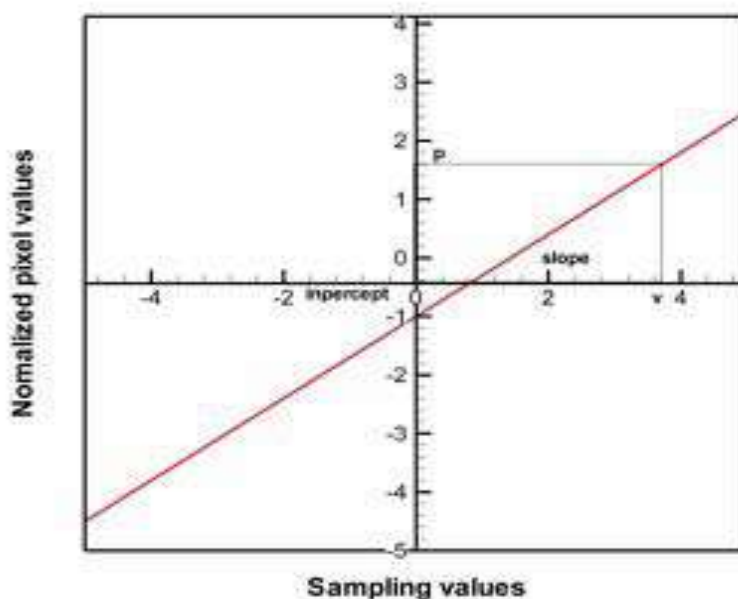


Figure A.7: Pixel linear normalization

Pixel data normalization

Quite often the pixel data, retrieved from DICOM standard, need to be normalized in order to display the correct image. For instance, sample values of common Roentgen represent the density of X-ray beam. The density values need to be transformed and normalized in pixel data.

The CT data, the so-called Hounsfield units need to be altered in order to have a correct representation of the medical image. The normalization of the pixel is only applied to gray-scaled data and two methods are available. These methods are the linear and non-linear normalization [145].

Linear normalization

By linear normalization a linear transformation of the gray scale values of the image takes place. The values of the *Rescale Slope* and *Rescale Intercept* attributes, should be given in order to perform the linear normalization. With the help of linear normalization, we perform a gray scale transformation, as shown in Figure A.7

The equation of the liner normalized pixel values is given by (A.1):

$$\text{PixelValue} = \text{Slope} * \text{SampleValue} + \text{Intercept} \quad (\text{A.1})$$

Non linear normalization

In some image modalities, such as ultrasound scanners, we use a nonlinear transformation between the acquired ultrasound data and the pixel representation. Unfortunately, DICOM standard till today does not provide any property to store the function parameters of the nonlinear function [145]. Colour palettes are placed, instead. The colour palette is stored in attribute values of the DICOM standard. Look-up table descriptors are used. Therefore, in DICOM standard for each color layer a look-up table is given. A look-up table consists of three successive 4-digit data, which provides:

- the number of entries of each look-up table in 8 bit sample values normally
- the first pixel value of the look-up table, and all other underlying values are shown with that pixel value
- the number of bits, which each look-up table needs

A sample value of a color layer of the pixel data sequence has to be interpreted as an index of its related look-up table. In that way the normalized pixel data produced.

Colour models

Besides the gray scaled colour of the pixels the resolution could be reached to 16 bits, various colour models can be used in DICOM standard.

RGB Model

Three fundamental colour models are RGB [146] (user in colour computer graphics and colour television); YIQ, YUC, or YCbCr (used in broadcast and television systems), and HSV (Hue Saturation Value). All of the colour spaces in common use can be derived from the RGB information supplied by the devices like cameras and scanners.

When light refracts through a prism, its colour components separate to create a rainbow. This rainbow is a spectrum particular to white light and the colour range that the human eye can perceive. The colours proceed across the spectrum in the order red, orange, yellow, green, blue, indigo and violet to give the acronym ROYGBIV. Of these colours, the primaries are red, green and blue, and the colour model for light is referred to as the RGB model.

The red, green, and blue (RGB) colour space is widely used throughout computer graphics and imaging. Red, green and blue are three primary additive colours (individual components that are added together to form a desired colour) and are represented by a three-dimensional, Cartesian co-ordinate system (The Colour Cube).

A diagonal from one corner of the cube (Black) to the other (White) represents various grey levels. The RGB colour space is the most prevalent choice for graphic frame buffers because colour CRT's use red, green, and blue phosphors to create the desired colour. Therefore, the choice of the RGB colour space for a graphics frame buffer simplifies the architecture and design of the system. Also, a system that is designed using the RGB colour space can

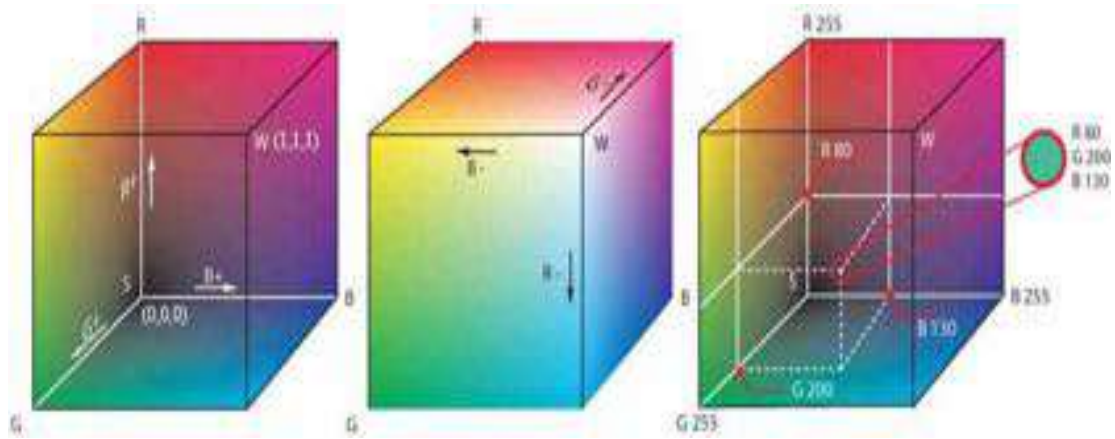


Figure A.8: The RGB colour cube with black at 0,0,0, white at 1,1,1, and primary and complimentary colours on the vertices.

take advantage of a large number of existing software routines, since this colour space has been around for a number of years.

However, RGB is not very efficient when elaborating with *real-world* images. All three RGB components need to be of equal bandwidth to generate any colour within the RGB colour cube. The result of this is a frame buffer that has the same pixel depth and display resolution for each RGB component. Also, processing an image in the RGB colour space is not the most efficient method. For example, to modify the intensity of a given pixel, the three RGB values must be read from the frame buffer, the intensity or colour calculated, the desired modifications performed, and the new RGB values calculated and written back to the frame buffer.

In the RGB model, each colour appears in its primary spectral components of red, green and blue. This model is based on a Cartesian coordinate system. The colour subspace of interest is the cube shown in Figure A.8, in which RGB values are at three corners.

$$\begin{bmatrix} \text{Black} \\ \text{White} \end{bmatrix} = \begin{bmatrix} R \\ R \end{bmatrix} = \begin{bmatrix} G \\ G \end{bmatrix} = \begin{bmatrix} B \\ B \end{bmatrix} = \begin{bmatrix} 0 \\ 255 \end{bmatrix} \quad (\text{A.2})$$

CIE RGB

In the study of the perception of color, one of the first mathematically defined color spaces was the CIE 1931 XYZ color space (also known as CIE 1931 color space), created by the International Commission on Illumination (CIE) in 1931 [147] [148].

Since the human eye has three types of color sensors that respond to different ranges of wavelengths, a full plot of all visible colors is a three-dimensional figure. However, the concept of color can be divided into two parts: brightness and chromaticity. For example, the color white is a bright color, while the color grey is considered to be a less bright version of that same white. In other words, the chromaticity of white and grey are the same while their brightness differs.

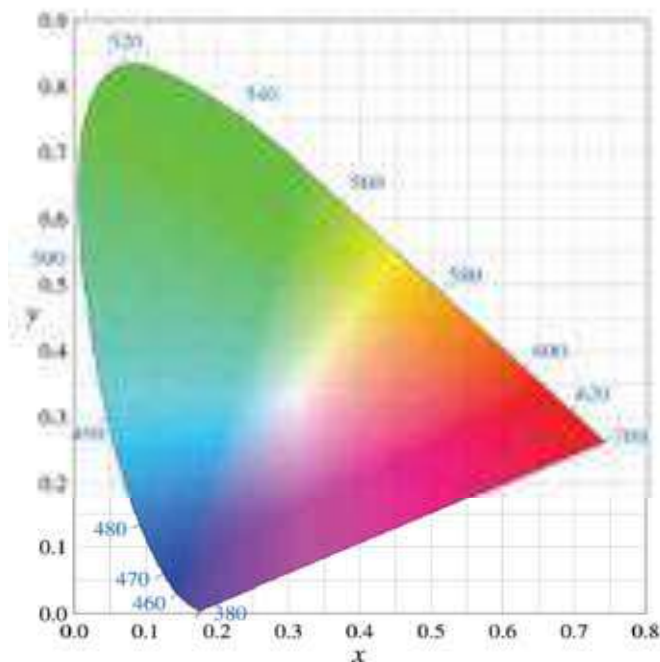


Figure A.9: The CIE 1931 color space chromaticity diagram

The CIE XYZ color space was deliberately designed so that the Y parameter was a measure of the brightness or luminance of a color. The chromaticity of a color was then specified by the two derived parameters x and y , two of the three normalized values which are functions of all three tristimulus values X , Y , and Z (A.3):

$$\begin{aligned} x &= \frac{X}{X+Y+Z} \\ y &= \frac{Y}{X+Y+Z} \\ z &= \frac{Z}{X+Y+Z} = 1 - x - y \end{aligned} \quad (\text{A.3})$$

The derived color space specified by x , y , and Y is known as the CIE xyY color space and is widely used to specify colors in practice. The X and Z tristimulus values can be calculated back from the chromaticity values x and y and the Y tristimulus value (A.4):

$$\begin{aligned} X &= \frac{Y}{y}x \\ Z &= \frac{Y}{y}(1 - x - y) \end{aligned} \quad (\text{A.4})$$

The figure A.9 shows the related chromaticity diagram. The outer curved boundary is the spectral locus, with wavelengths shown in nanometers. Note that the chromaticity diagram is a tool to specify how the human eye will experience light with a given spectrum. It cannot specify colors of objects (or printing inks), since the chromaticity observed while looking at an object depends on the light source as well. Mathematically, x and y are projective coordinates and the colors of the chromaticity diagram occupy a region of the real projective plane.

The CIE RGB colour space is one of many RGB color spaces, distinguished by a particular set of monochromatic (single-wavelength) primary colors.

In the 1920s, Wright [149] and Guild [150] independently conducted a series of experiments on human sight which laid the foundation for the specification of the CIE XYZ color space.

The results were summarized by the standardized CIE RGB color matching functions $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, and $\bar{b}(\lambda)$, obtained using three monochromatic primaries at standardized wavelengths of 700 nm (red), 546.1 nm (green) and 435.8 nm (blue).

The color matching functions are the amounts of primaries needed to match the monochromatic test primary. These functions are shown in the plot on the right (CIE 1931). Note that $\bar{r}(\lambda)$ and $\bar{g}(\lambda)$ are zero at 435.8, $\bar{r}(\lambda)$ and $\bar{b}(\lambda)$ are zero at 546.1 and $\bar{g}(\lambda)$ and $\bar{b}(\lambda)$ are zero at 700 nm, since in these cases the test color is one of the primaries. The primaries with wavelengths 546.1 nm and 435.8 nm were chosen because they are easily reproducible monochromatic lines of a mercury vapor discharge. The 700 nm wavelength, which in 1931 was difficult to reproduce as a monochromatic beam, was chosen because the eye's perception of color is rather unchanging at this wavelength, and therefore small errors in wavelength of this primary would have little effect on the results.

The color matching functions and primaries were settled upon by a CIE special commission after considerable deliberation. The cut-offs at the short- and long-wavelength side of the diagram are chosen somewhat arbitrarily; the human eye can actually see light with wavelengths up to about 810 nm, but with a sensitivity that is many thousand times lower than for green light. These color matching functions define what is known as the *1931 CIE standard observer*. Note that rather than specify the brightness of each primary, the curves are normalized to have constant area beneath them. This area is fixed to a particular value by specifying (A.5)

$$\int_0^{\infty} \bar{r}(\lambda) d\lambda = \int_0^{\infty} \bar{g}(\lambda) d\lambda = \int_0^{\infty} \bar{b}(\lambda) d\lambda \quad (\text{A.5})$$

The resulting normalized color matching functions are then scaled in the r:g:b ratio of 1:4.5907:0.0601 for source luminance and 72.0962:1.3791:1 for source radiant power to reproduce the true color matching functions. By proposing that the primaries be standardized, the CIE established an international system of objective color notation. Given these scaled color matching functions, the RGB tristimulus values for a color with a spectral power distribution $I(\lambda)$ would then be given by (A.6):

$$\begin{aligned} R &= \int_0^{\infty} I(\lambda) \bar{r}(\lambda) d\lambda \\ G &= \int_0^{\infty} I(\lambda) \bar{g}(\lambda) d\lambda \\ B &= \int_0^{\infty} I(\lambda) \bar{b}(\lambda) d\lambda \end{aligned} \quad (\text{A.6})$$

HSV Model

The HSV model is commonly used in computer graphics applications. In various application contexts, a user must choose a color to be applied to a particular graphical element. When used in this way, the HSV color wheel is often used. In it the hue is represented by a circular region; a separate triangular region may be used to represent saturation and value. Typically the vertical axis of the triangle indicates saturation, while the horizontal axis

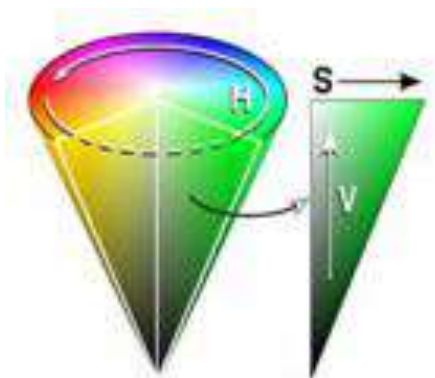


Figure A.10: The HSV colour cone

corresponds to value. In this way, a color can be chosen by first picking the hue from the circular region, then selecting the desired saturation and value from the triangular region.

Another visualization method of the HSV model is the cone. In this representation, the hue is depicted as a three-dimensional conical formation of the color wheel. The saturation is represented by the distance from the center of a circular cross-section of the cone, and the value is the distance from the pointed end of the cone. Some representations use a hexagonal cone, or hexcone, instead of a circular cone. This method is well-suited to visualizing the entire HSV color space in a single object; however, due to its three-dimensional nature, it is not well-suited to color selection in two-dimensional computer interfaces.

The HSV color space could also be visualized as a cylindrical object; similar to the cone above, the hue varies along the outer circumference of a cylinder, with saturation again varying with distance from the center of a circular cross-section. Value again varies from top to bottom. Such a representation might be considered the most mathematically accurate model of the HSV color space; however, in practice the number of visually distinct saturation levels and hues decreases as the value approaches black. Additionally, computers typically store RGB values with a limited range of precision; the constraints of precision, coupled with the limitations of human color perception, make the cone visualization more practical in most cases, as shown in Figure A.10.

YUV Model

The basic equations for converting between gamma-corrected RGB and YUV are (A.7) and (A.8):

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 \\ -0.147 \\ 0.615 \end{bmatrix} * R + \begin{bmatrix} 0.587 \\ -0.289 \\ -0.515 \end{bmatrix} * G + \begin{bmatrix} 0.114 \\ 0.436 \\ -0.100 \end{bmatrix} * B \quad (\text{A.7})$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} * Y + \begin{bmatrix} 0 \\ -0.394 \\ 2.032 \end{bmatrix} * U + \begin{bmatrix} 1.140 \\ -0.581 \\ 0 \end{bmatrix} * V \quad (\text{A.8})$$

For digital RGB values with a range of 0 to 255, Y has a range of 0 to 255, U a range of 0 to 112 and V has a range of 0 to 157

CMY Model

In MCY model, instead of the accumulated colours as RGB model, subtractive primary colours are used. This model uses the Cartesian coordination system like RB. The difference is that the primary colours used are cyan, magenta and yellow. Those colours are the complementary colours of red, green and blue. The conversion matrix is the following (A.9):

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (\text{A.9})$$

where the assumption is that all colour values have been normalized to the range [0,1].

That model is primarily applied to colour printers. Most devices that deposit color pigments on paper require CMY data input or perform an RGB to CMY conversion, internally. It demonstrates that light reflects from a surface coated with pure cyan does not contain red ($C = 1 - R$).

Colour models in DICOM

As we saw in the above sections, the pixel data can be represented in various colour models. Since the algorithms of the image presentation in a colour model must be applied, it makes sense to apply a transformation, in which the resources uses must be low.

In the following table an overview of the various colour systems is given, along with the photometric interpretation property.

In DICOM, gray values are mostly stored in MONOCHROME2.

In MONOCHROME2 the gray values are represented in a row of one bit (1Bit) value for black/white images only add till sixteen bit (16Bits) values for images with up to 216 gray levels. In this connection, the black are represented with the lowest bit values and the white with the highest values. The decision for the transformation of all gray levels in images is used, due to:

- Majority of the DICOM images are already in photometric interpretation of MONOCHROME2, therefore a transformation is not needed.
- MONOCROME2 will be better represented on the raster displays, where higher pixel values are brighter gray levels.

Under the photometric interpretation of RGB, the transformation of RGB colour models is realized. The pixels, included in the imaging data set, are divided into three layers. Each colour layer represents a primary colour.

As in MONOCHROME2, higher pixel values represent brighter colours. The reason for transforming RGB model for the image representation, and thus for the transformation

Photometric Interpretation	Colour model	Conversion
MONOCHROME1	1 to 16 Bit Gray values in colour layout, by which the lowest value is white.	In Gray value alike MONOCHROME2
MONOCHROME2	1 to 16 Bit gray value in a colour layout, by which the lowest value is black	No conversion needed
PALETTE COLOR	Colours in 3 Pallets for Red, Green and Blue	in RGB
RGB	Colours in 3 layouts for Red, Green and blue.	No conversion needed
HSV	Colours in 3 layouts for hue, saturation and luminance	in RGB
CMYK	Colours in 4 layouts for Cyan, Magenta, Yellow and Black	in RGB
YBR_FULL	Colours in 3 layouts, one for Luminance (Y), and two for Chrominance (CB und CR)	in RGB

Table A.4: Transformation of used colour models

of values of other colour models into RGB model is the same as for the MONOCROME2 transformation for gray level images.

Shortly after DICOM standard for the RGB colour model 8 Bits for each colour has been allocated. This is the reason why in a gray level images, represented into RGB with same values of the colour layer must be anticipated and MONOCROME2 is used. In RGB model would only possible 28 gray values. The majority of the images in DICOM format are gray level images with more than 8 bits. In that situation image information is going to be lost.

Geometrical transformation

In two dimensions (2D) numerous of geometrical transformation can be applied [151]. In the following sections we give an overview of the available geometrical transformation.

Scaling transformation

The scaling transformation $S(s_x, s_y)$ of the pixel matrix with the scaling factors s_x and s_y , is given with the help of the scaling matrix, as shown by equation (A.10).

$$S(s_x, s_y) = \begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix} \quad (\text{A.10})$$

s_x is the scaling factor into X-axis and s_y is the scaling factor into Y-axis. Thus, the scaling transformation equation for each pixel value (x,y) is given by (A.11).

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix} * \begin{pmatrix} x \\ y \end{pmatrix} \quad (\text{A.11})$$

Rotation transformation

The rotation transformation is able to rotate the image to a given angle. The rotation transformation matrix has the form of the equation (A.12).

$$R(\theta) = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \quad (\text{A.12})$$

Shear transformation

A transformation in which all points along a given line remain fixed while other points are shifted parallel to by a distance proportional to their perpendicular distance from. There are two types of shear transformation, which allow points along to x-axis or y-axis in connection to their coordination, to be displaced. The transformation matrix is given by the equation (A.13) and (A.14).

$$SH_x(a) = \begin{bmatrix} 1 & a \\ 0 & 1 \end{bmatrix} \quad (\text{A.13})$$

$$SH_y(b) = \begin{bmatrix} 1 & 0 \\ b & 1 \end{bmatrix} \quad (\text{A.14})$$

The shearing transformation equation for each pixel value (x,y) with a constant of proportionality and b constant (shear on x-axis) is given by equation (A.15).

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = SH_x(a) * \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} x + ay \\ y \end{pmatrix} \quad (\text{A.15})$$

Translation

To displace an image into two directions (x, y) with displacement (d_x, d_y), we define the displacement vector (A.16).

$$T(d_x, d_y) = \begin{pmatrix} d_x \\ d_y \end{pmatrix} \quad (\text{A.16})$$

Finally, the new point (x', y') will be given by the equation (A.17)

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} d_x \\ d_y \end{pmatrix} \quad (\text{A.17})$$

Combination of geometric transformation

Combining geometrical transformation, it would be easier to use homogeneous coordinates for each transformation. Then the translation can be calculated as a product instead of sum. Additional transformations can be used multiplying their transformation matrices. The points would be presented in a homogeneous way using the equation (A.18)

$$P = \begin{pmatrix} x/w \\ y/w \\ w \end{pmatrix} \quad (\text{A.18})$$

If we set $w = 1$ the transformation matrices have the forms:

$$P = \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \quad (\text{A.19})$$

$$S(s_x, s_y) = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (\text{A.20})$$

$$R(\theta) = \begin{bmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (\text{A.21})$$

$$SH_x(a) = \begin{bmatrix} 1 & a & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (\text{A.22})$$

$$T(d_x, d_y) = \begin{bmatrix} 1 & 0 & d_x \\ 0 & 0 & d_y \\ 0 & 0 & 1 \end{bmatrix} \quad (\text{A.23})$$

Now, scaling a point $P = (p_x, p_y)$, we firstly need to place that point on the (x, y) system and to scale and finally to transfer the point to the initial system. So, the following equation (A.24) depicts the transformations in place.

$$M = T(p_x, p_y) * S(s_x, s_y) * T(-p_x, -p_y) \quad (\text{A.24})$$

If we would like to perform a displacement d_x and d_y the equation shall shown as in equation (A.25)

$$M = T(d_x, d_y) * T(p_x, p_y) * S(s_x, s_y) * T(-p_x, -p_y) \quad (\text{A.25})$$

or in the matrix form:

$$M = \begin{bmatrix} 1 & 0 & d_x \\ 0 & 1 & d_y \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & p_x \\ 0 & 1 & p_y \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & -p_x \\ 0 & 1 & -p_y \\ 0 & 0 & 1 \end{bmatrix} \quad (\text{A.26})$$

$$M = \begin{bmatrix} s_x & 0 & p_x(1-s_x)+d_x \\ 0 & s_y & p_y(1-s_y)+d_y \\ 0 & 0 & 1 \end{bmatrix} \quad (\text{A.27})$$

So, for the scaling p_x and p_y as well as for the displacement of points, we need finally to calculate the matrix, as given by (A.28):

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{bmatrix} s_x & 0 & p_x(1-s_x)+d_x \\ 0 & s_y & p_y(1-s_y)+d_y \\ 0 & 0 & 1 \end{bmatrix} * \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \quad (\text{A.28})$$

A.3 Instant messaging protocols

A.3.1 ICQ

ICQ [152] was originally developed by the company Mirabilis. The first official version made its first appearance in November 1996. In 1998 the protocol was bought by AOL, which developed it further. ICQ uses two channels for communication: a client-server connection as well as a client-client connection [153]. By means of the client-server connection registration data, presence data and other tag information normally are transferred but no messages. For the transmission of chat messages ICQ uses in each case a client-to-client direct connection among the recipients, as illustrated in Figure A.11. If this connection is not possible, the messages are transferred via the server. The transmission thereby can be based on TCP or UDP.

The last version of the ICQ protocol was ICQ99. With ICQ2000 a modified version of the AOL/Oscar-protocol is used.

A.3.2 AOL/Oscar

Oscar (Open System for CommunicAtion in Realtime) protocol [154] is a part project of the Instant Messaging System of the company AOL. The Oscar-architecture basically consists of two components, as shown in Figure A.12:

1. the Authorization Server which takes over the registration of the user,
2. the BOS (Basic Oscar Service)-Server.

For the communication TCP connections are used. The user, before using the application, has to register into the Authorization Server. The authorisation is performed by making use

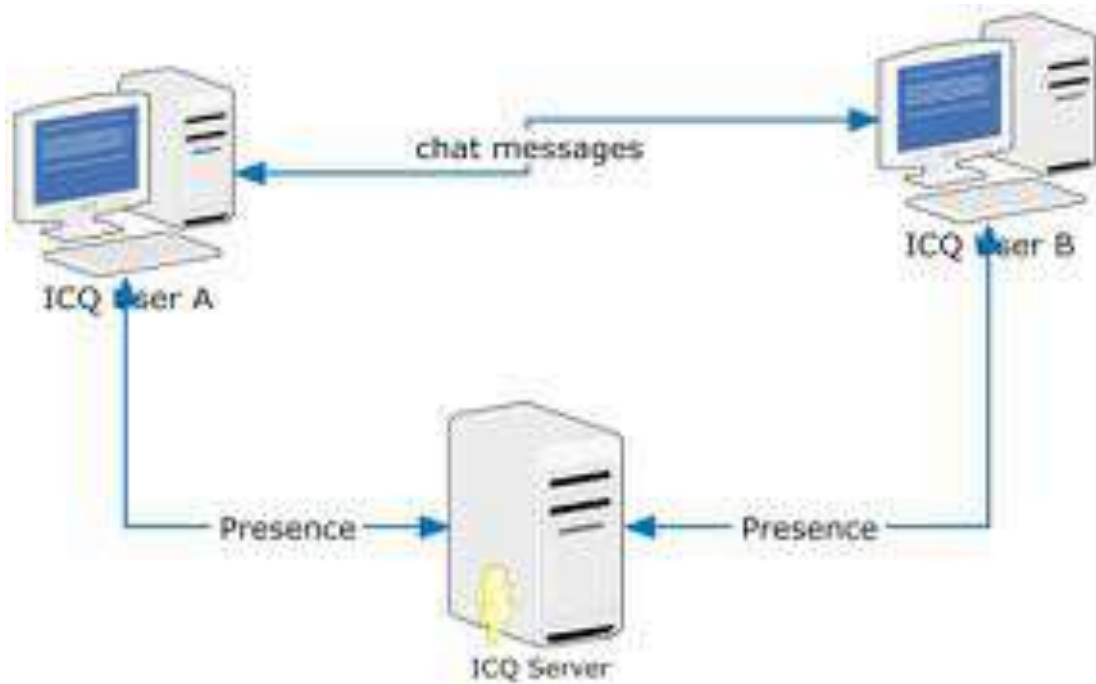


Figure A.11: ICQ communication schema: Direct communication

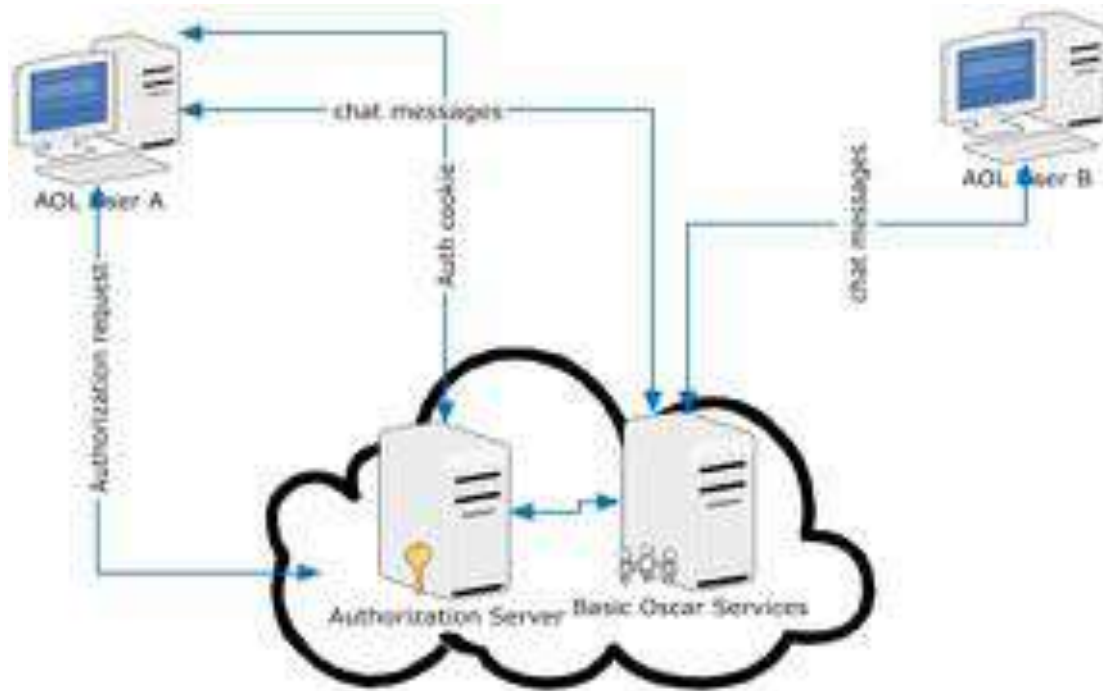


Figure A.12: AOL communication schema

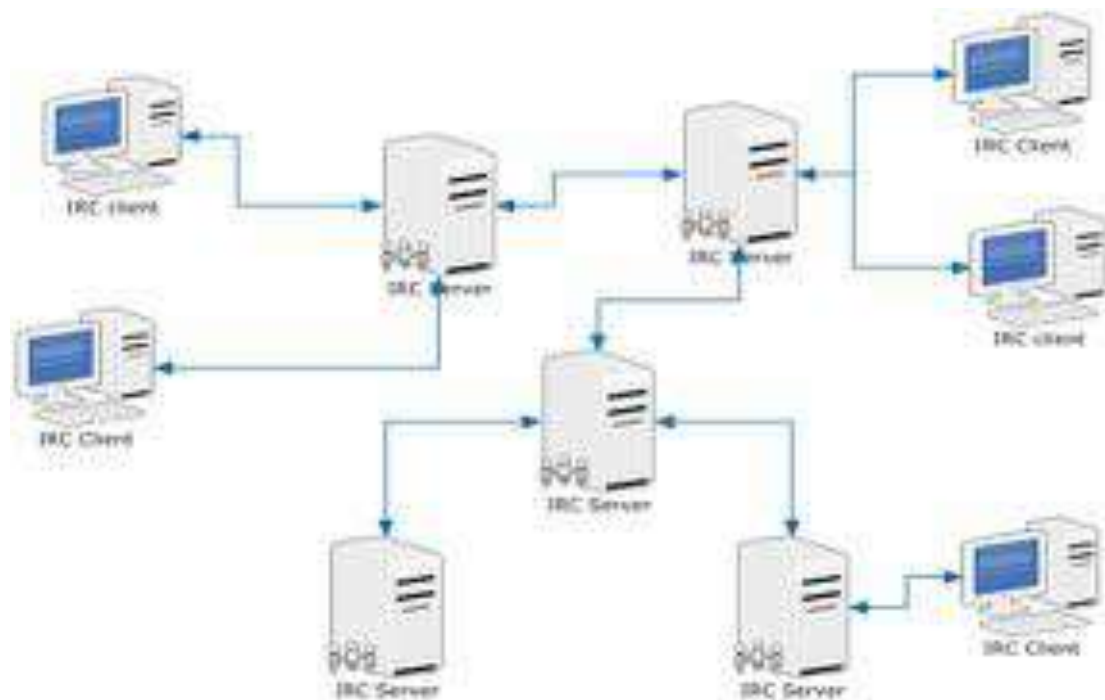


Figure A.13: IRC network

of a user name and a password. After successful registration, the user receives a Cookie from the Authorization Server which allows the use of a BOS-Server. With the help of the BOS Server chat messages can be exchanged.

A further component of the AOL-Instant Messaging-System is the TOC-Protocol [155]. Via TOC alternative clients may use the AOL-Instant Messaging-System. It uses however a very limited functional range and is not used by official clients.

A.3.3 IRC

The IRC (Internet Relay Chat) protocol was introduced by Oikarinen [155] and published in 1993 in RFC 1459. In 2000 the specifications in RFC 1459 were replaced by four new RFCs. The RFCs 2810-2813 included the IRC-architecture, the management of chat-channels as well as the client and server specifications.

As the development of the IRC-net started years before publication of the protocol specifications in RFC 1459, it is probably the oldest still used chat protocol [155]. The protocol itself shows a teleconference system. The users can enter different chat rooms and communicate there with like-minded people.

Furthermore IRC includes a private chat, where a user communicates solely with a chosen user. This *private chat* is comparable with the chat functionality of Instant Messaging systems today. IRC also offers the user a limited form of online presence; only the status forms *online*, *offline* as well as *away* are supported. If the user is offline, he cannot receive any messages.

IRC chat systems are organized in form of IRC networks independent from each other. A

user can be addressed clearly via a user name only within one network. A network overall communication is often not provided. An IRC-network is shown in Figure A.13. Each server in a network knows its own clients. The clients are addressed clearly by a pseudonym in the network. The communication always runs through the servers and there is no direct connection among the users [156].

In order to avoid the communication over the server, many IRC clients make use of DCC (Direct Client to Client) connections [157]. The data thereby are exchanged from client to client via a direct TCP-connection. Herewith it is also possible to exchange data.

A.3.4 SIP/SIMPLE

The SIP (Session Initiation Protocol) protocol [158] serves as development of meetings. It is used for example in new VoIP (Voice over IP) -internet phones- for establishing of connections (signalling calls). The real voice data can be transferred via RTP (Realtime Transfer Protocol). A work group of IETF is working on an extension of the SIP-protocol.

By means of SIMPLE (SIP for Instant Messaging and Presence Leveraging Extensions) Instant- Messaging news and presence information can be transferred via the SIP-protocol. This extension has been published in RFC3428 as internet standard.

SIMPLE messages consist of a header and a body. This message construction is similar to e-mail. The header specifies information of the recipient and the sender. The body includes afterwards the message content. Messages are transferred in a SIP (inquiry) packet. This packet thereby can pass several proxies till it reaches the recipient. Furthermore SIMPLE messages can temporally be stored, in case the recipient is not reachable.

A.3.5 Skype

Skype is a peer-to-peer (p2p) VoIP client developed by the organization that created Kazaa. Skype allows its users to place voice calls and send text messages to other users of Skype clients [159]. In essence, it is very similar to the MSN and Yahoo IM applications, as it has capabilities for voice-calls, instant messaging, audio conferencing, and buddy lists. However, the underlying protocols and techniques it employs are quite different. Like its file sharing predecessor Kazaa, Skype uses an overlay peer-to-peer network.

There are two types of nodes in this overlay network, ordinary hosts and super nodes (SN). An ordinary host is a Skype application that can be used to place voice calls and send text messages. However, the communication protocol is not known and therefore it cannot be applied and extended to medical needs, when needed. Figure A.14 shows a simplified network topology where skype clients are connected to different super nodes and the communication is implemented via the server communication.

A.3.6 Jabber/XMPP

Jabber [80] is a free, XML-based protocol for Instant Messaging and online-presence. Most of the parts of the protocol were worked out by the Jabber developer team in 1999. In 2002 an IETF work group was founded in order to create a standard.

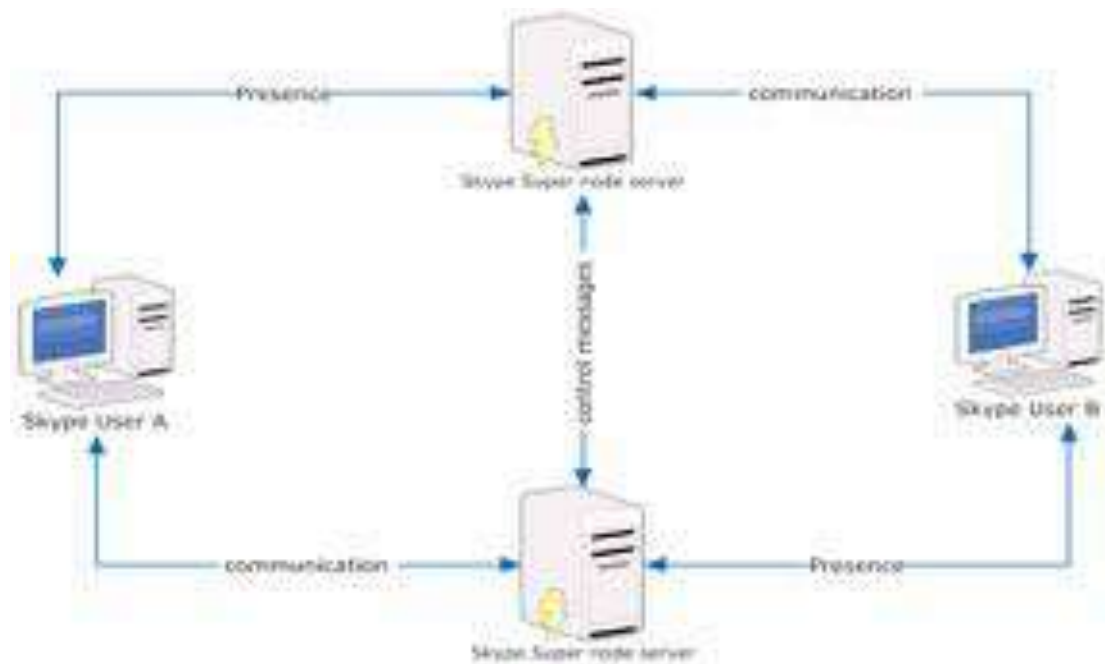


Figure A.14: A skype network topology

In 2004 the developed protocol was published under the name of XMPP (Extensible Messaging and Presence Protocol) in four RFCs as (proposed) internet standard. This is characterised by a larger functional range opposite to Jabber. Principally it is a matter of XML-Routing Framework.

Furthermore, in terms of payload, complex functions preferably are implemented on the server. The client should include only small functionality and thereby be easy to implement. The jabber clients should run on light devices with limited CPU and intermediate memory capacity. Recipients are addressed from XMPP via a Jabber ID (JID). In the simplest form the JID is similar to an e-mail address:

userName@jabberServerName.TLD.

For instance, physician1@hospitalB.org. These names are easy to memorise. The messages reach the remote user via a S2S (server to server) protocol. Opposite to IRC, a Jabber server does not have to recognise all users and servers. From the JID of the recipient, the DNS name of the remote Jabber Server can be extracted. The server can be connected via the S2S protocol with each user-defined server. This is shown in Figure A.15. This procedure is similar to e-mail systems.

Furthermore, the functionality of the Jabber/XMPP-protocol can be extended by so-called JEPs (Jabber Enhancement Proposals). JEPs can be specified and published by everyone. Thematic discussions on the submitted JEPs are made in the Standard-JIG-mailing list. An example of JEP is the HTTP polling protocol. This is presented in following chapter. With HTTP poling protocol a connection to a Jabber server can be established making use of HTTP.

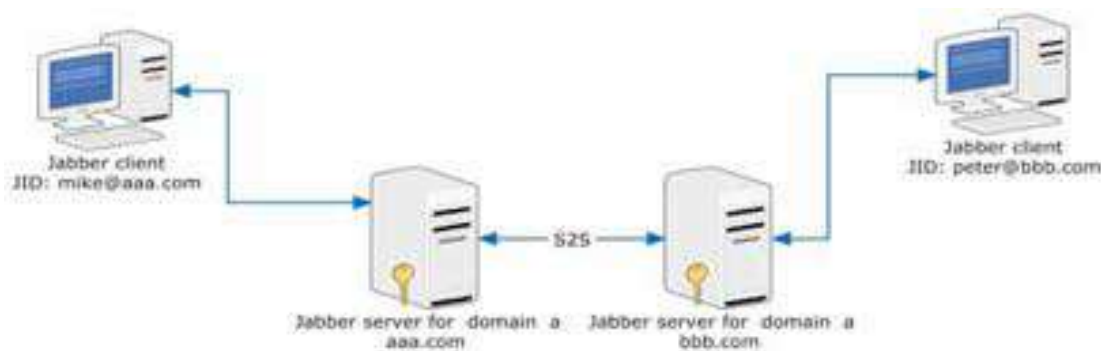


Figure A.15: Messages exchange over Jabber protocol between two registered users on different servers.

HTTP polling protocol

In general, a firewall is a box that protects a network from outsiders, by controlling the IP connections that are allowed to pass through the box. Often, a firewall will also allow access outside only by proxy, either explicit proxy support or implicit through Network Address Translation (NAT) (Figure A.16).

In the interest of security, many firewall administrators do not allow outbound connections to unknown and unused ports. Until Jabber becomes more widely deployed, port 5222/tcp (for Jabber client connections) will often be blocked.

The best solution for sites that are concerned about security is to run their own Jabber server, either inside the firewall, or in a DMZ network. However, there are network configuration where an external Jabber server must still be used and port 5222/tcp outbound cannot be allowed.

In these situations, different methods for connecting to a Jabber server are required. Several methods exist today for doing this traversal. Most rely on the fact that a most firewalls are configured to allow access through port 80/tcp. Although some less-complicated firewalls will allow any protocol to traverse this port, many will proxy, filter, and verify requests on this port as HTTP. Because of this, a normal Jabber connection on port 80/tcp will not suffice.

In addition, many firewalls/proxy servers will also not allow or not honor HTTP Keep-alives (as defined in section 19.7.1.1 of RFC 2068) and will consider long-lived socket connections as security issues. Because of this the traditional Jabber connection model, where one socket is one stream is one session, will not work reliably.

In light of all of the ways that default firewall rules can interfere with Jabber connectivity, a lowest-common denominator approach was selected. HTTP is used to send XML as POST requests and receive pending XML within the responses. Additional information is prepended in the request body to ensure an equivalent level of security to TCP/IP sockets.

The client makes HTTP requests periodically to the server. Whenever the client has something to send, that XML is included in the body of the request. When the server has something to send to the client, it must be contained in the body of the response.

In some browser/platform combinations, sending cookies from the client is not possible due

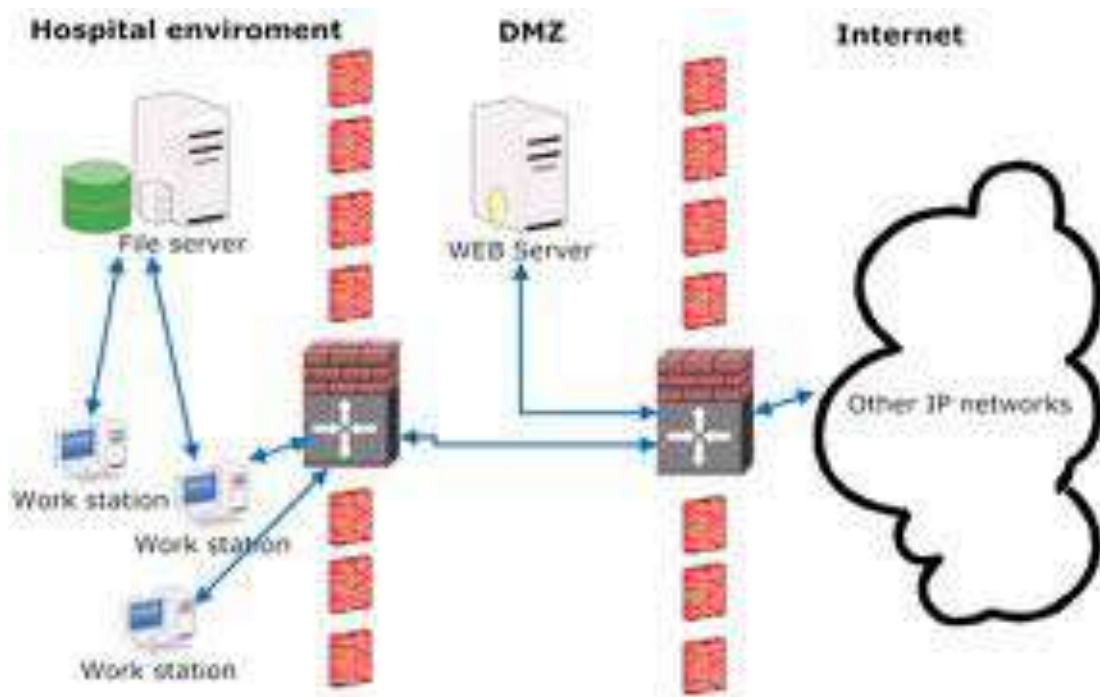


Figure A.16: Hospital's firewall protected network

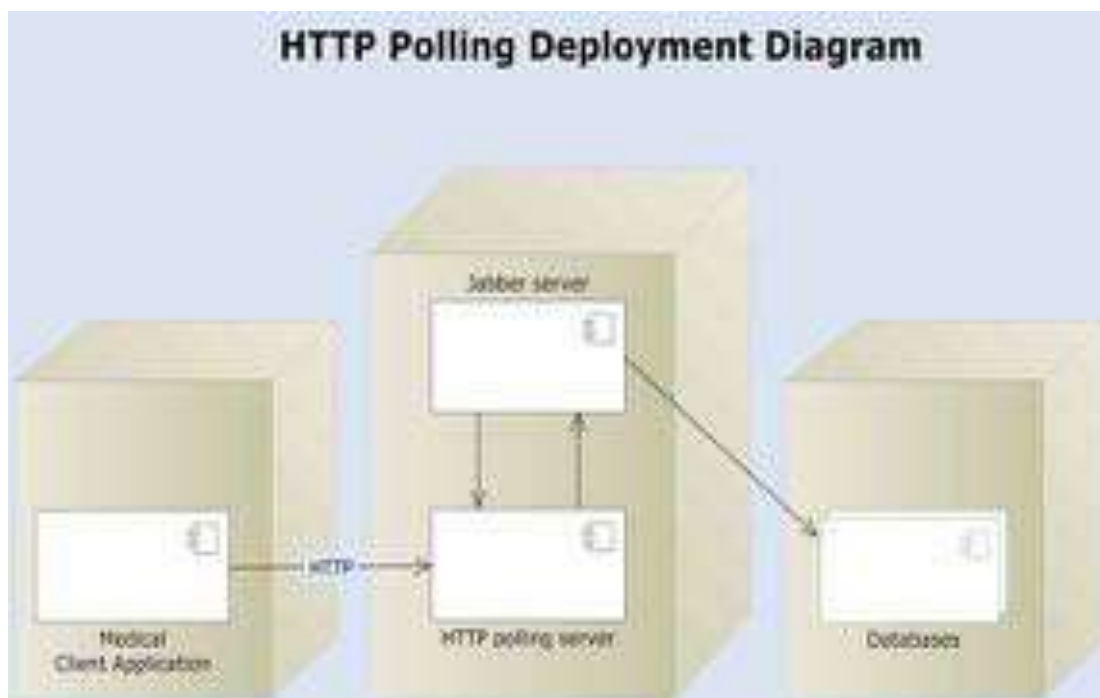


Figure A.17: HTTP polling deployment diagram

to design choices and limitations in the browser. Therefore, a work-around was needed to support clients based on these application platforms.

All requests to the server are HTTP POST requests, with Content-Type: application/x-www-form-urlencoded. Responses from the server have Content-Type: text/xml. Both the request and response bodies are UTF-8 encoded text, even if an HTTP header to the contrary exists. All responses contain a Set-Cookie header with an identifier, which is sent along with future requests as described below. This identifier cookie must have a name of 'ID'. The first request to a server always uses 0 as the identifier. The server must always return a 200 response code, sending any session errors as specially-formatted identifiers.

Appendix B

TeleInViVo

Image scaling

Stretch ratio and angle should be represented in an original and accurate way. That way deformation and corruption of the image is avoided. Otherwise, the physician would give the wrong interpretation of the displayed data.

Also, an image rotation makes little sense, due to the fact that image direction is defined from the DICOM attributes. Through this, we also avoid wrong interpretations, and, for instance, we could not mistake the right with the left hemisphere of the brain in a CT image data set.

Furthermore optimizations with regard to the displayed speed as to shear strains and rotations are not certainly possible. But it is absolutely vital to zoom in interesting details in the image or reduce radiograms which are often very large. It is also essential to adjust the image in order to see remote image sections on the screen again or to center important details in the windows display.

The scaling was restricted. Angles in the image would change with different scaling factors S_x and S_y due to the scaling, as shown in Figure B.1 In order to maintain the angles in the image and thus the section proportions when scaling or zooming, S_x and S_y have to be identical. Therefore the uniform scaling is used with

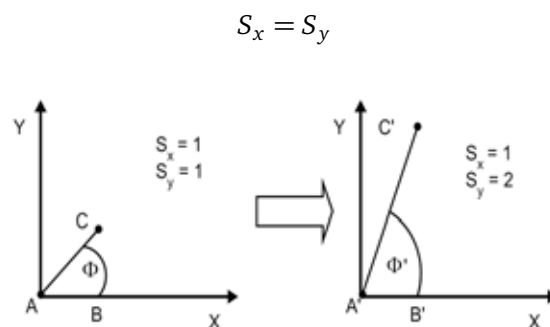


Figure B.1: Change of angle at non-uniform scaling

Image interpolations

Numerous suitable interpolation methods exist which can be applied after scaling to pixel of the new image. They differ with regard to the optic result of the output image and the calculating effort to create it. Here are the four plainest and most commonly used interpolation methods:

- the Nearest Neighborhood Interpolation, pixels appear as a homogeneous surface in big-scaled images thus requiring the least calculating effort [160]
- the Bi-Linear Interpolation, reducing raster in extended images compared to the Nearest Neighborhood Interpolation including four pixels altogether, thus meaning increased calculating effort [161]
- the Bi-Cubic Interpolation, reducing the blurring possibly caused by the bi-linear interpolation and further counteracting raster at very extended images, causing however, highest calculating effort and thus strongest slowdown of image buildup [162]
- the interpolation according to the Algorithm of Fant, being speed-optimised by separated interpolation of lines and columns. Results similar to the Nearest Neighborhood or the bi-linear interpolation can be achieved according to weighting of the surrounding pixel values [163]

Histogram operations

In order to increase the readability of the output image, the user can manipulate and adjust image quality by means of the image histogram. Two operations seem to make sense [164, 165, 166, 167, 168, 169]:

- The stretching of the histogram leads to an increased contrast in the image. By elimination of grey/colour values lying in the surrounding areas of the histogram it is possible to distribute the more often grey/colour values in the middle lightness area to a broader spectrum. By that, nearby lying values can be shown with stronger differing intensity and thus larger contrast. The stretching of the histogram is realised by linear transformation of grey values.
- The leveling of the histogram, also called linearisation of the histogram, can help to see image points which would not be visible due to the low contrast with regard to other image points. It is assumed that the quality of the image increases when levelling the histogram; in cases where the grey values included are distributed as equal as possible over the number of pixel that means that all grey values appear even often as possible. When linearising the histogram the lightness values of very frequent pixels are drawn apart and distributed to a broader spectrum whereas rare grey/colour values are reduced. Thus frequent image points which therefore have a lower contrast, e.g. the image background, can often be visible then. The leveling of the histogram represents a non-linear RGB/grey-value transformation.

Filter operations

Due to the fact that there are a lot of possible filter operations which can be used in the particular image it is very difficult to give the required operations to the user. Goals of various filter operations differ totally. On the one hand, the size of the used pixel neighborhood is important for the result quality of a filter operation, on the other hand is the negative effect on the speed of processing when using a big filter matrix. The goal of filtering fault pixel is a further contradiction, thus unfortunately increasing the blurring of the image and rejection of borders and fineness in the image [170, 171]. When implementing it should be emphasized:

- a sufficiently large flexibility by the user when choosing the filter;
- a minimization of loss of performance when showing filtered images.

The required flexibility is achieved when giving the possibility of defining his own filters to the user. This possibility should be accomplished by predefined filters the user can apply unchangeably but which he can also modify or extend. The definition of own filters shall not only contain the setting of the filter matrix and the scaling factor but also some useful settings for applying the operators and their combination.

The loss of performance with regard to the demonstration speed can be restricted to a unique waiting time when generating and filling buffers for filtered image data. The buffering of filtered images enables the display without any time lag compared to the display of original data, except for the waiting time necessary when choosing a new filter operation in order to apply the new filter at the original image and buffer data.

Additional functionality

At first it has to be considered what can be displayed and what is useful to be displayed. In principle all attributes coded in a data file can be displayed. Hereby it has to be distinguished between displaying attribute values directly or transforming them before. A decision which information should be overlaid to the image in the main display was made as follows:

- The depth of layer for example shows the position of the displayed layer at the z-coordinate at 3-D data sets of CT images. The images of one issue are arranged according to the depth of layer
- The modality so that the viewer knows which kind of image is shown
- The name of the patient, the date of birth of the patient and the patient ID should always be shown with the image so that a confusion of test results of different patients can be excluded
- The date of the examination can be compared with the date of birth of the patient for example in order to determine his age at the time of the examination. Furthermore it can be easily distinguished between different examinations with the help of the date

- Displays of orientation for the image are shown by most of the DICOM visualisation programmes. They are to avoid a side confusion of the image for example. They show the orientation of the display detail of the patient relative to the display area of the image
- X- and Y-Metering bars indicate measured values of physical measurement of lengths along the two center lines of a picture and allow estimates of the real size of the image which can be difficult at scaled images

There is of course a lot of additional information which can possibly be very important for diagnosis. There should be the possibility to visualise all DICOM attributes so that the user can find all information from the DICOM data sets. As the information assigned to the DICOM-structure by the parser is restricted to a small choice of attributes in the data set, an additional small parser has to read the attributes and decode for the display.

Measuring instruments

It is often necessary to make measurements in the displayed images. Above all there is longimetry and goniometry as illustrated in Figures B.2 and B.3. These can only be offered for images for which the relation of the pixel rate of the original image to physical quantities for indications of length are indicated in the corresponding DICOM file. Thereby it is important to see that the physical pixel lengths in direction of the x-axis of the image can quite differ from those in direction of the y-axis. The following three kinds of measuring make sense for the destination of measures of different image contents:

- The simple longimetry between two points of the image displayed. This is to determine distances or diameters for example to determine the diameter of a cranial section etc
- Measuring of the angle between two distances. This function is not that often used like the one to determine distances, however, it completes this with the possibility of establishing a connection of three anatomically significant points
- Measuring of a total distance composed of several sections. This allows the rough determination of measure for example approximated by setting of suitable segments of distance by the user.

The processing mode

The processing mode displays time-shifted images consecutively in the right sequence so that there is the impression of movement in the image. It is an advantage when the user himself can determine frame rate, start and end of the sequence to be played. The DICOM-module is to give the user absolute freedom in fixing start and final image of a sequence. Merely the frame rate is to be restricted to maximum values in case these extend the possibilities of the computer. Moreover, the user is to be always informed of the actual number

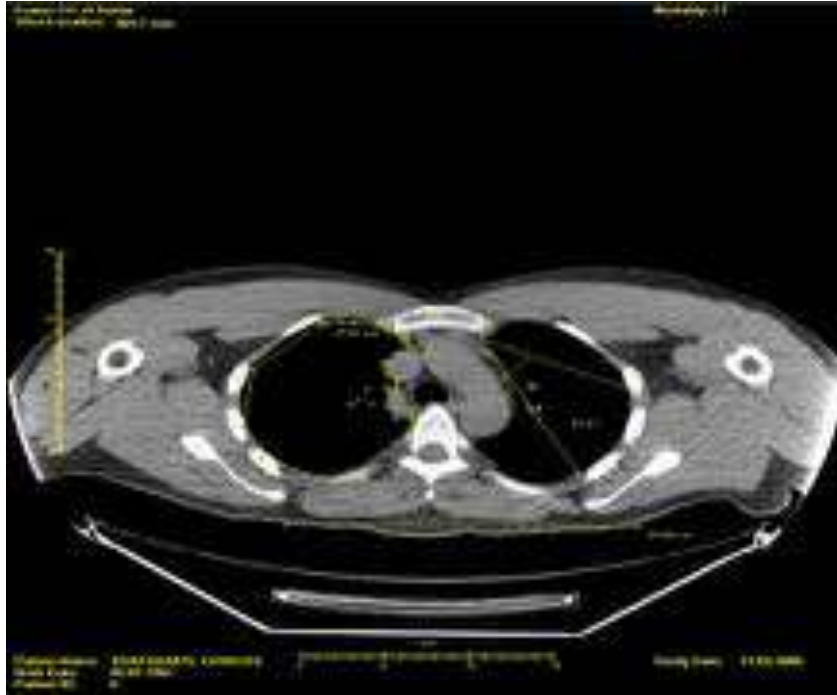


Figure B.2: Measuring distances on DICOM modalities

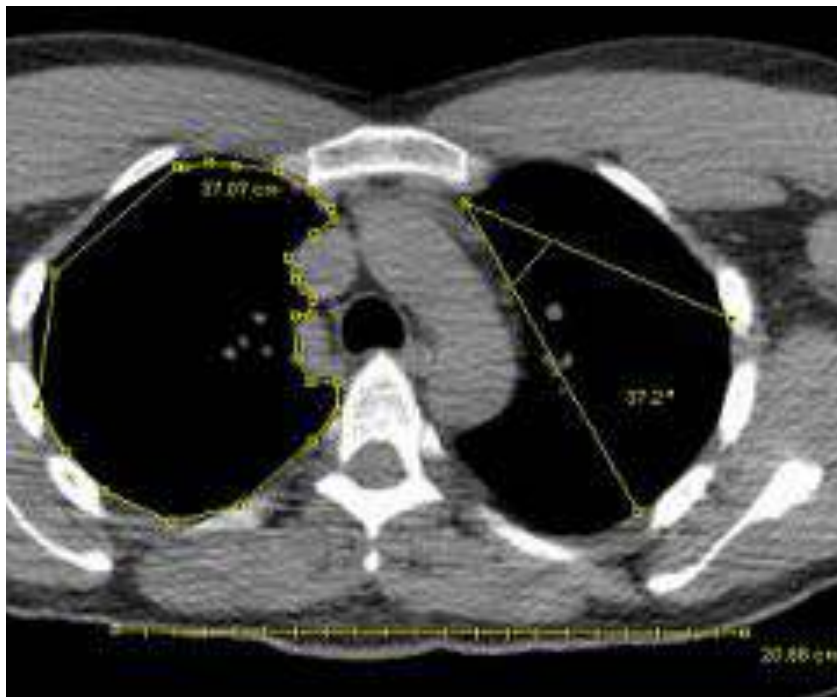


Figure B.3: A closer view of measuring distances

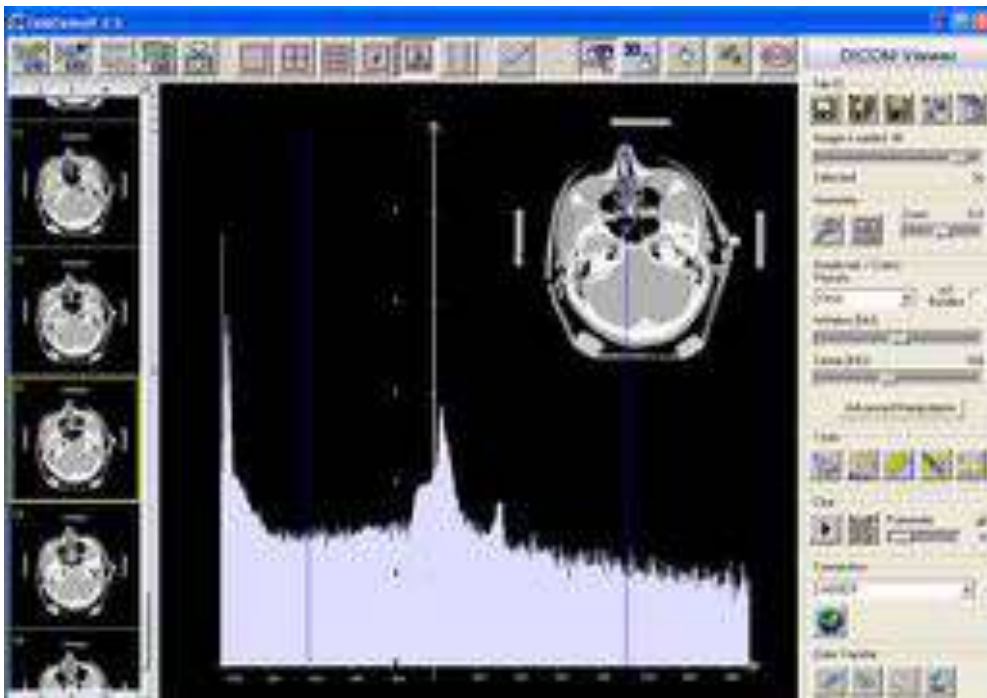


Figure B.4: Histogram view of CT data

of images per second so that he is able to interpret the *moved* image. A sorting of the images so that the right sequence is reached when playing does not have to be considered as the images are already correctly sorted when loading and pasting in the DICOM real world structure. Thereby time-shifted images of a data file are available in the way that the image shows the first image of a sequence at the time t_0 and the following are sorted in ascending order.

The histogram display

In case of a histogram in a one-dimensional array, the frequency values easily can be applied over a scale. The user, however, has to receive scaling possibilities for the axes of the histogram. As the frequencies within a histogram differ strongly it is otherwise impossible to recognize very low values. A logarithmic presentation of frequencies would be a further step to assure better recognisability or readability. The presentation of a histogram of an image alone is not very significant for the user. In order to optimise the window/center positions, for example by means of the histogram, it makes sense to still show the window in the histogram. Furthermore it is often very difficult to relocate the significant frequency of a grey value to the positions in the image. For that reason the user shall be able to highlight grey-value regions in the histogram which then are pointed out in a two-dimensional image.



Figure B.5: Representation of 3D data sets: CT sample

The 3D-display

The 3D-display is to present images in a series with different layer depths (mostly CT images) in the way that the connection of single layers can be recognized. For that purpose it is sufficient to turn the 3D-object round an axis which simplifies the algorithm shown. As there possibly is no connected object out of the single CT-layers with big layer distance, it shall be possible to see the layers *unconnected*, as well as produce connections among the layers as well as artificial angles. An essential factor in recognizing a three-dimensional image is which pixel values are transparent: that means do not hide pixels underneath. It is obvious to assume transparency for black pixels. The transparency region can be moved via transformation of grey value. In case of a Hounsfield position for example showing only bones material, the CT images would show the whole surrounding tissue parts transparently and thus the bones only three-dimensionally.

The user interface

This mostly deals with 3D-visualization of ultrasound images using a quartered display window for the view out of different perspectives. The DICOM-module requires a window in which the loaded image data, as well as additional notes to the image, is shown in the standard display. It makes sense to enable further views for the comparison of data besides the standard view of only one image. The following display modes have featured in the application:

- Standard view of one image only

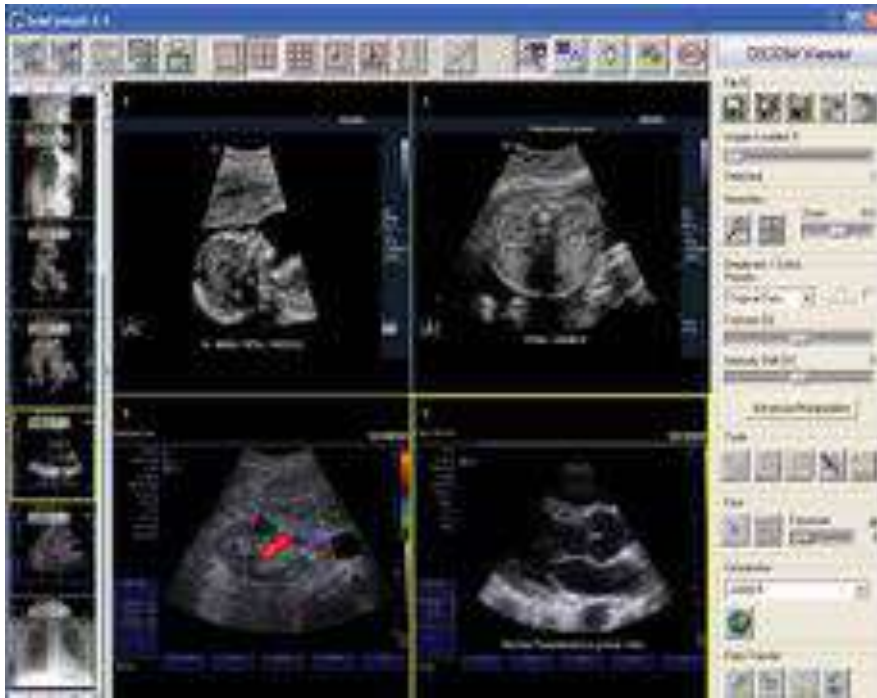


Figure B.6: User interface in 2x2 view

- Quad view for comparison of up to four images side by side
- Ninesome view for comparison of up to nine little images side by side
- View for DICOM attributes issued as text
- View for the histograms to loaded images
- View of layers of 3D data sets

Medical database

Server database

The Database server is an optional service, as illustrated in Figure B.7. This service is used for the operation of our medical collaboration application in a clinical network. It makes it possible for several clients/workstations to access the same database and medical data. If a clinic wants to hold the data for all their medical workstations centrally in one place, it is necessary for them to use one PC as their database server. Every database client now has to be connected to the database server to access the medical data. Swapping out of data and data backup must now be done on the server instead of each workstation.



Figure B.7: Database server user interface

Client database

The Client database is the interface between the main medical imaging application and the database file as shown in Figure B.8, where patient, studies, images and messages are stored permanently. Over the same graphical user interface, it is possible to access a database, where the data is stored locally on the workstation or to access data which is held centrally on a database server, e.g. in a clinical network. Figure B.9 shows the user interface of the database client. The main parts of the GUI are:

- The Main Menu
- The Tool Bar
- The List of Patients and Studies
- The List of Data
- The Preview Window
- The Status View
- The Status Bar

With the client database the following operations are possible:

- Creation, modification and deletion of patients.
- Creation, modification and deletion of studies.



Figure B.8: From user interface to database

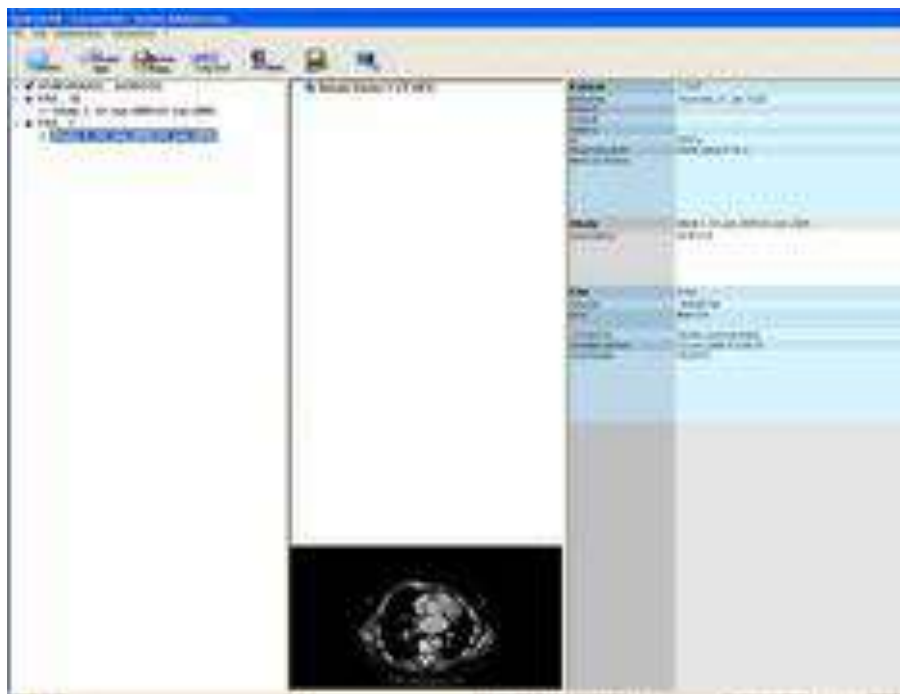


Figure B.9: Client database user interface

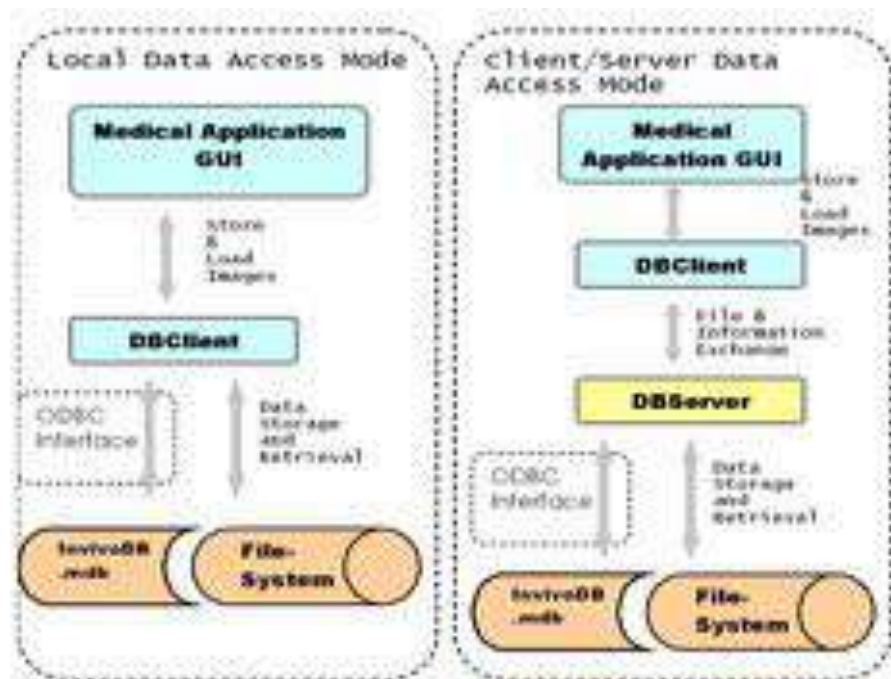


Figure B.10: Local and Client/Server Data Access Mode

- Storing of images, configurations, videos and other (additional) files assigned to a patient and study.
- Swapping out data (images) to other storage medias, whereby the purpose is to prohibit the local hard disk of getting full.
- Export and Import of patients/studies and images to external files, whereby the purpose is the exchange of data between several TeleConsult databases.
- Loading of images, configurations and videos into TeleConsult.
- Importing of DICOM images via DICOM network into the Database.
- Sending and receiving of messages, together with patient, study and image information from and to other TeleConsult workstations (Offline Messaging)

Figure B.10 shows the difference between the two modes of data access. The first mode is used with standalone workstations and the second for workstations operating in a clinical environment with more than one workstation accessing the same database over a repository server.

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