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Emergency TeleOrthoPaedics m-health system for wireless communication links

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Abstract: For the first time, a complete wireless and mobile emergency TeleOrthoPaedics system with field trials and expert opinion is presented. The system enables doctors in a remote area to obtain a second opinion from doctors in the hospital using secured wireless telecommunication networks. Doctors can exchange securely medical images and video as well as other important data, and thus perform remote consultations, fast and accurately using a user friendly interface, via a reliable and secure telemedicine system of low cost. The quality of the transmitted compressed (JPEG2000) images was measured using different metrics and doctors opinions. The results have shown that all metrics were within acceptable limits. The performance of the system was evaluated successfully under different wireless communication links based on real data.

1 Introduction

In general, 40% of the cases in the Accident and Emergency Department of a hospital are cases of orthopaedics. The question whether orthopaedics incidents are classified by doctors as easy or difficult, in order to decide the appropriate immediate actions to be taken, arises in most of these cases. Therefore the need of a second opinion is evident depending on the incident itself as well as on the experience and the self-confidence of the doctor involved in each case. This paper presents a useful tool for doctors when they need a second opinion during the confrontation of emergency orthopaedics incidents. Doctors can exchange securely medical images and video as well as other important data, and thus perform remote consultations, fast and accurately using a user friendly interface, via a reliable and secure telemedicine system of low cost.

Modern healthcare systems are expected to be able to correspond to the following emerging social challenges: (i) the need of offering high-standard medical care, with the highest possible accuracy, promptly, and with minimum cost, (ii) the exploitation of growth of technology and also of science (medicine, pharmacology, biotechnology, molecular biology/genetic) for the provision of direct, more specialised and also more effective medical care, which is often achieved with the consultation between doctors remotely and (iii) the need for more rational use of human and economic resources, which are available for health. Additionally medical systems are expected to respect and satisfy the patients' rights, needs and expectations, towards having access to the opinion of expert doctors confidentially, anywhere and anytime.

Mobile health can be defined as the use of PDAs, tablet computers, subnotebooks, smart phones, wireless networks, mobile hardware peripherals and all related software for healthcare. Rapid advances in information technology and telecommunications, and more specifically wireless and mobile communications, and their convergence (telematics) are leading to the emergence of a new type of information infrastructure that has the potential of supporting an array of advanced services for healthcare [1–9]. A range of deployment options such as cellular phone systems are used for telemedicine applications, such as the transmission of blood measurements [10] and transmission of medical data and video conferencing [11]. In recent years, fixed telemedicine systems related to orthopaedics have been developed. A 'Web-based home telemedicine system for orthopaedics' is presented in [12], which is for asynchronous multimedia messaging between shoulder replacement surgery patients at home and their surgeons. A web browser plug-in was developed to simplify the process of capturing video and transferring it to a web site. The video capture plug-in can be used as a template to construct a plug-in that captures and transfers any type of data to a web server. Other examples include the 'remote consultation in orthopaedics', which deals with remote consultation with junior orthopaedic trainee-based in a community clinic utilising real-time medicine [13] and the 'PH-Net project' [14] for supporting local administrations and care providers to analyse the different aspects of using ISDN network for the interconnection of healthcare telematics applications in the UK. One of the objectives of this project is the analysis of the delay times needed to share clinical images from conventional X-ray, CT and MRI for a real interactive consulting service. Statistical tests (ROC curves) are applied to confirm that the diagnostic accuracy obtained on a computer monitor from the planned telemedicine applications remains comparable with the conventional diagnostic accuracy. The University of Rochester Medical Center in New York employs an ATM backbone network that supports rates at 155.52 Mbps (OC-3) and interoperates with Ethernet, Fast Ethernet and Gigabit Ethernet network segments. This network provides access to patient records and enables transmission of X-rays, CT and MRI scans, and angiograms; it also supports videoconferences and teleconsultations between hospital-based physicians and inmates at local jails [15].

Another project is the Canadian Rural Medicine Network (CARMEN). The ISDN infrastructure of this project supports interactive videoconferences and teleradiology teleconsultations between radiologists at metropolitan hospitals and primary care physicians at rural clinics. The CARMEN ISDN platform also enables transmission of patient X-rays and CT scans from rural clinics to major urban hospitals for enabling telediagnosis and determining treatment plans [16].

This paper presents for the first time a complete wireless and mobile teleorthopaedic system with field trials and expert opinion. Further, this paper investigates the GSM, general packet radio service (GPRS) and universal mobile telecommunications system (UMTS) mobile standards and SMTP and FTTP protocols for the orthopaedic system. The operation of the Emergency TeleOrthoPaedics System (ETOPS) is consistent with the general spirit of telemedicine 'communication anywhere and at anytime'. As soon as the expert doctor studies the data and the relevant information regarding the received request, he can give immediately his opinion to the medical attendant who exploits it towards the confrontation of the incident. The above process may take place anytime and may last only a few minutes with the participation of two or more doctors who may be in different places. The particular system employs Internet technologies and various types of modern computer devices and is based on the use of wired channels as well as wireless channels.

The paper is organised as follows. In Section 2, an overall description of the ETOPS is presented including security issues. Section 3 describes the processes and protocols regarding image capturing, processing and quality assessment, and Section 4 presents the performance of the system. Finally, Section 5 concludes the paper.

2 System description

ETOPS shown in Fig. 1 has been developed on a prototype level and applied with minimal cost on a pilot basis in two main hospitals in Cyprus, Nicosia and Paphos General Hospitals. The system is a useful tool for doctors, when they need a second opinion during the confrontation of mainly emergency orthopaedics incidents and has been developed within the frame of collaboration of the Ministry of Health of Cyprus, the orthopaedic clinics of the above hospitals, the Higher Technical Institute, Nicosia, Cyprus, the University of Cyprus, Brunel University, UK and the Cyprus Telecommunications Authority. It is a relatively small but also a cost-effective telemedicine system, which can serve the needs of doctors in cases of second opinion in emergency orthopaedics.

The major features of the system are described as following:

- Provides the efficient means of communication between expert doctors while being in the same hospital;

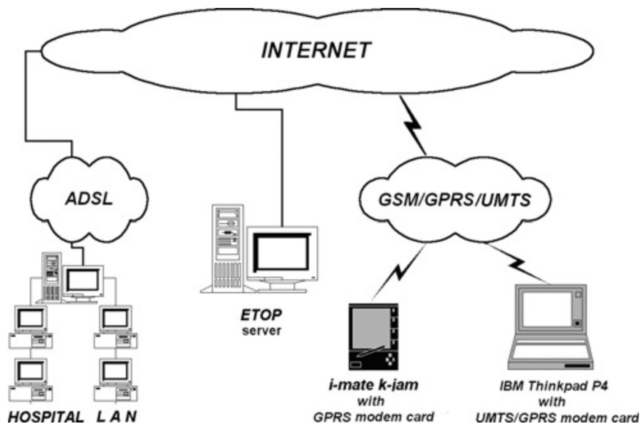

Figure 1 *Network infrastructure of the ETOPS*

- Provides efficient means and convenient methods for establishing communication between expert doctors independently from where they are;

- Establish communication from the operating theatre with an expert doctor;

- Establish communication by ambulance with an orthopaedics doctor in a hospital;

- Establish communication between a doctor of Rural Sanitary Centre and an expert orthopaedics doctor in a central hospital;

- Doctors can exchange securely medical images and video as well as other important medical data.

The basic functional components of the service are a web server that hosts the web service, a database server which holds the service information and remote clients who are able to connect to the Internet. These devices must be capable of handling digital certificates. Critical factors regarding the system's successful implementation are usability, performance and security. The server side is separated into two different zones; the public and the private zones, which are distinguished by the level of security they have. All telemedicine service data will be exchanged over a secure socket layer (SSL) channel. The asymmetric cryptography algorithm of this SSL channel is based on mutual authentication; encryption is provided using the public key infrastructure (PKI) technology.

2.1 Hardware

Orthopaedics doctors can exchange securely X-rays, photographs and video as well as other data with one or more experts via the Internet, by the use of desktop PCs or laptop or handheld devices via the GPRS wireless channels as well as via 3G technologies namely UMTS. The communication is carried out in minimal time via the orthopaedics server that is connected to the Internet. GPRS and UMTS systems provide the advantage to the doctor/user to have his wireless computer connected to the Internet continuously. In the Nicosia General Hospital four desktop PCs form the Orthopaedics local area network. The LAN as well as the Orthopaedics Server, is connected to the Internet via a fixed IP 1 Mbps ADSL connection. Doctors also have at their disposal digital cameras that facilitate storage of a large number of very high-resolution image files, as well as video files. In the future, when an electronic X-ray scanner will be available in the department the digitisation process will become even faster. The captured TIFF images, once selected by the user–doctor, are automatically converted into JPEG2000 format using a simple and user friendly interface and then an automatic connection to the server is established via the Internet, provided the client is already certified. The doctor is allowed to use the telemedicine service once he is identified to be a valid user.

2.2 Methodology and protocol of use

During emergency incidents while the patients are already in the hospital or while patients are being carried to the hospital by an ambulance, doctors can exchange medical images, video as well as patient records, in the form of simple and functional electronics forms employing the user interface as shown in Fig. 2. During exchange of videos, the quarter common intermediate format (QCIF) standard is recommended that is a standard related to CIF standard and transfers one fourth of the amount of data, and is suitable for systems on slower connections or telephone lines. CIF is a video format that supports both NTSC and PAL signals, the CIF is part of the ITU H.261 videoconferencing standard. It specifies a data rate of 30 frames per second (fps), with each frame containing 288 lines and 352 pixels per line.

After the expert is informed via Email or SMS that his opinion is required, he can provide it immediately via the web site of the system, the address of which will be included in the message he received. This information will be incident oriented and stored in the incident database keeping a code link with the corresponding electronic patient record, which will be stored in a separate-offline database.

2.3 Software

The software was designed such that after the authentication of a user he enters into the main webpage where he has the options to: (i) insert an incident (ii) check if there are any alerts for him (iii) check if there are any responses for his previous requests for second opinion (iv) study the records of all the cases he was previously involved, either for requesting or giving an opinion and (v) search for any incidents recorded in the data base that has to be studied.

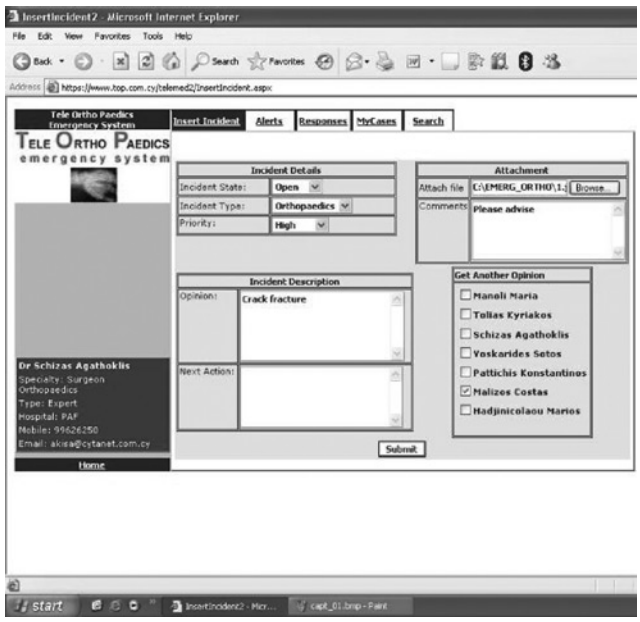

Figure 2 *'Insert Incident' page of the prototype application*

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In the case of inserting an incident, the user has the options, through pull down menus, of choosing the state, the type and the priority of the incident. He can give a short description of the incident and the proposed next action, as well as attach the necessary file or files and provide his comments. He can choose from a list of doctor(s) to conduct and then submit his request to the system.

2.4 Security

The communication between ETOPS users can be established on any TCP/IP network connected to the Internet. Although any Internet connection can support the communication of a client-server session, such as a dial-up connection, fast networks are proposed such as digital subscribers lines (DSL) up to 2 MBps for wired networks and UMTS up to 384 KBps for wireless networks. The server side hosts the services and the data exchanged and is thus the most important component of the telemedicine service. It is separated into two different zones, which are distinguished by the level of security they have. In the public zone that can be accessed only by telemedicine users, all data and relevant information is exchanged. The private zone accommodates the following services: telemedicine service, authentication, certificate authority (CA), mail server, database server and the PKI portal that is the web interface servicing the registration process as well as other PKI processes like renewal and certificate revocation list (CRL) download that cannot be accessed by the users. Through this PKI portal, administration tasks such as issuing a certificate are completed instantly in a secure fashion [17, 18].

The telemedicine service that receives a vast amount of requests that must be serviced within seconds, is the core service of this system, and thus its high availability is mandatory. All data exchanged within the telemedicine service propagates over an SSL channel as shown in Fig. 3. The asymmetric cryptography algorithm of this SSL channel is based on mutual authentication – server to client and client to server – raising the required computational power even more. For all these reasons, the proposed design is similar to PKI portal, clustered server in load-balancing mode equipped with stream of SSL accelerators.

Availability is a serious concern for all the service's elements. For this reason cluster architecture with two nodes is implemented. Additionally, the operating system of the two nodes is in the local storage of the servers in a RAID-1 (mirror) configuration.

The cluster operates in a fail-over mode (ACTIVE – PASSIVE), meaning that only one node will be functional in each time. This eliminates the possibility to suffer from cluster problems such as database inconsistencies, emanating from known issues such as transactions replication. This design ensures the high availability of the

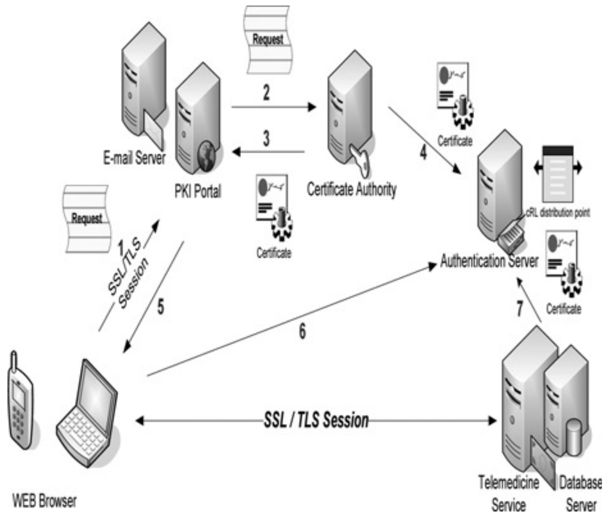

Figure 3 *Telemedicine service abstract network diagram*

server and minimises the downtime in case of a disaster. Connections to PKI portal use the HTTPS protocol on port 443, which is an HTTP connection over an SSL tunnel. SSL protocol is using a combination of symmetric and asymmetric cryptography in order to encrypt the data exchanged over the secure channel.

The authentication service is provided between the users and certificates. Authentication is essential for both the registration and operation process. During the registration process authentication is used in order to match the username/password combination to certificate users. During the operation process authentication is used to match certificates to system users. It is obvious that authentication is mandatory to operate constantly since a possible failure of it will leave the telemedicine service in a non-operational mode. The proposed design architecture for the authentication service is the building of a domain, which consists at least of three domain controllers. One of the domain controllers operates as the schema master and the other two as replicas. To eliminate the possibilities of a disaster, the schema master is in a cluster like the PKI portal. Since the domain controllers are operating in parallel, each one servicing different requests, this design provides high availability for this service while improving performance as well.

The CA is servicing two major operations; the certificate insurance and the publication of CRLs. The infrastructure is focused in network availability. For this reason a node of at least two issuing servers is proposed. The two servers operate in parallel in load balancing mode. Finally there are two additional CAs, the policy CA in the private zone for more flexibility, and the root CA, which is offline to maintain physical security.

The Mail and Database servers are parts of the telemedicine service. The Mail server is used in order to

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alert doctors in case of an emergency and the Database server is used in order to hold information exchanged between the telemedicine users. The services hosted in the private zone of the system are being populated to the users through the telemedicine Web Site found in the public zone. There is a secure connection between the public and private zone, which is inaccessible by the users, to enable the system to provide all the required services to users in a secure fashion.

For security reasons a master–slave topology is implemented. The slave is placed in the public zone and the master in the private zone. The telemedicine service has write access to the slave database. The master database pulls data after validating them, in a periodical schedule.

3 Image quality

3.1 Orthopaedics digital library

Images from the orthopaedics digital library of the Orthopaedics Clinic at Nicosia Hospital were employed for the performance analysis of the ETOP system. This library consists of 24 images covering all possible skeletal X-rays that orthopaedic surgeons may face in their everyday clinical practice excluding spinal images. The categorisation of the X-rays of the library is shown in Table 1. All X-rays

Table 1 Categorisation of X-rays of the orthopaedics digital library

X-ray	Library image number	Type	Comments
ankle	1	D	crack fracture of the lateral malleolus undisplaced fracture, shown only on lateral X-ray
	2	E	displaced fracture of the medial malleolus
elbow	3	D	undispaced fracture of the head of radius
	4	E	displaced fracture of the head of radius
femour	5	D	transverse fracture of a previously was plated femour
	6	E	displaced spiral fracture of the famour
form arm	7	D	crack fracture of the ulna
	8	E	dislaced fracture of the radius
foot	9	D	very small avalsion fracture. (i) can cause doubts if is normal or not (ii) can raise the question whether to operate or not
	10	E	angulated fracture of the first metatarsal
hand	11	D	avalsion fracture of the proximal phalanx of the thumb
	12	E	displaced fracture of the head of the fifth metacarpal
humerus	13	D	crack fracture of the neck of the humerus
	14	E	displaced fracture of the humerus
knee	15	D	small exostosis of the upper tibia. Can be easily missed or misdiagnosed
	16	E	displaced fracture of the lateral tibial condole
pelvis	17	D	impact fracture of the head femour (anatomy of femour not disturbed)
	18	E	displaced fracture of the petric ring
shlder	19	D	crack fracture of upper part of humerus
	20	E	displaced fracture of the head of humerus
tibia	21	D	crack fracture of the fibula (seen only on lateral X-ray)
	22	E	displaced fracture of the tibia
wrist	23	D	greenstick fracture of the distal radius
	24	E	displaced fracture of the distal radius

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were collected from the Accident & Emergency (A&E) Department as well as from the fracture clinic of the Nicosia General Hospital, with the aim to assess the performance of the system. These X-rays were classified as 'difficult cases' (D) and 'easy cases' (E). The quality of the X-rays was not a decisive factor for their selection, since the source was mainly the usually very busy A&E Department.

3.2 Image capture

All X-rays were digitised in order to be used in the system using a 5 Megapixel digital camera, Nikon CoolPix 5700 model and were transferred to a Compaq Tablet PC, with a 995 MHz TM5800 processor running Windows XP. The area of interest of each X-ray was predetermined using a 25.60 × 19.20 cm rectangular frame. The resulting TIFF images had dimensions of 2560 × 1920 pixels, consisting of a total of 5 × 1024 × 1024 square pixels with a spatial resolution of 100 μm, and with each pixel having a 24 bits depth [19].

3.3 Image compression

Three different image compression standards were investigated namely JPEG2000, JPEG and JPEG-LS. The JPEG2000 standard proved to be superior compared to the others.

The JPEG2000 standard was designed to overcome the limitations of the original JPEG standard and provide high-quality images at low bit-rates and provides a feature set vital to the medical imaging community. JPEG2000 has been selected for inclusion in the DICOM standard for medical image transfer. DICOM Supplement 61 was ratified in November 2001 adding JPEG2000 Transfer Syntaxes to the protocol. The benefits of JPEG2000, which make it appropriate for use in the orthopaedics telemedicine project [17, 20] are as follows: (1) JPEG 2000 offers greater compression while maintaining better quality than traditional JPEG. This helps to reduce network bandwidth and storage requirements. (2) It is the only 16-bit greyscale lossy compression supported in DICOM. (3) Maintains diagnostic image quality. (4) Multiple resolutions in JPEG2000 means that only the data needed to view the image for a particular device or zoom need be sent over the network and loaded into memory. (5) Progressive display provides feedback to the user while the image is loading. (6) It offers region of interest encoding and decoding. (7) It supports 24-bit colour, and 8, 12 and 16-bit greyscale image data. For the JPEG2000 the JasPer implementation (ISO/IEC JTC1/SC29/WG1) [21] was used. The standard (ISO/IEC 10918-1) was used in [22]. This standard specifies processes for converting source image data to compressed image data, processes for converting compressed image data to reconstructed image data, coded representations for compressed image data and gives guidance on how to implement these processes in practice. It is applicable to continuous-tone – greyscale or colour – digital still image data and to a wide range of applications, which require use of compressed images. It is not applicable to bi-level image data.

The implementation LOCO [23] was chosen for the study (ISO/IEC 14495-1). This standard defines a set of lossless (bit – preserving) and nearly lossless (where the error for each constructed sample is bounded by a pre-defined value) compression methods for coding continuous tone, greyscale or colour digital still images. This draft standard (a) specifies a process for converting source image data to compressed image data; (b) specifies coded representations for compressed image data and (c) provides guidance on how to implement these processes in practice [24].

3.4 Image quality assessment methodology

The 24 X-ray compressed images were assessed visually by ten expert doctors of the orthopaedic clinic of the Nicosia General Hospital as well as by MATLAB software.

Visual evaluation can be broadly categorised as the ability of an expert to extract useful anatomical information from an X-ray image. The visual evaluation varies of course from expert to expert and is subject to the expert's variability [25]. Once the maximum acceptable compression level (from TIFF to JPEG2000) was determined, the visual evaluation was carried out according to the ITU-R recommendations with the double stimulus continuous quality scale procedure [26].

All the visual evaluation experiments were carried out at the same laptop workstation under indirect fluorescent lighting typical of an office environment. The ten orthopaedic experts evaluated the images with the objective of evaluating the JPEG2000 image quality compared to the original X-ray itself.

The experts were allowed to position themselves comfortably with respect to the viewing monitor, where a typical distance of about 50 cm was kept. Experts in real-life applications employ a variety of conscious and unconscious strategies for image evaluation, and the aim was to create an application environment as close as possible to the real one.

3.5 Image quality assessment using quantitative metrics

Further to the quality evaluation carried out by experts, the differences between the original and the compressed images were evaluated using MATLAB employing image quality and nine evaluation metrics, which were used as statistical measures. The basic idea was to compute a single number that reflects the quality of the processed image. For the quality measure of the compressed images nine metrics were used. The various metrics are described in the Appendix. Table 2 shows the quality of the compressed

Table 2 Quality of the compressed (JPEG2000) images using MATLAB 7.0 for the 24 images of the X-ray library

		GAE	MSE	PSNR	RMSE	SNR	Err ($\beta = 3$)	Err ($\beta = 4$)	Q	SSIN
easy	MEAN (1–12)	0.0	13.6	39.1	3.5	30.5	4.2	4.9	0.4	0.9
	STD (1–12)	0.0	11.1	3.7	1.2	6.3	1.5	1.7	0.1	0.1
difficult	MEAN (13–24)	0.0	13.8	38.9	3.5	30.9	4.2	4.9	0.4	0.9
	STD (13–24)	0.0	11.1	3.6	1.2	6.5	1.4	1.6	0.1	0.1
all	MEAN (all)	0.0	13.7	39.0	3.5	30.7	4.2	4.9	0.4	0.9
	STD (all)	0.0	10.9	3.6	1.2	6.2	1.4	1.6	0.1	0.1

(JPEG2000) images based on nine different metrics using MATLAB 7.0 for the 24 images of the X-ray library. The first two rows refer to the 12 'easy' cases of Table 1, third and fourth rows to the 12 'difficult' cases and the last two rows all 24 cases together. All nine metrics used in the analysis have shown that are well within acceptable limits.

From the results in Table 2, it can be concluded that the JPEG 2000 format can be used for sending the medical images (X-rays and photos) using the orthopaedics telemedicine system with excellent results. In most cases with high-quality compression applied, the final result is visually indistinguishable to the human eye. Owing to its excellent coding performance and many attractive features, there is a very large potential application base for JPEG 2000.

4 Performance evaluation

4.1 Performance of the system using GSM, GPRS and UMTS channels

The performance of the system was evaluated using wireless communication channels during the transmission of medical images of varying size in the following cases: downloading of X-ray images via SMTP (as Email attachment) or via FTP using both GSM and GPRS, and downloading of images via FTP over GPRS. In addition the performance of the GPRS system using FTP access was evaluated in the cases of repetitive downloading of a video file of size 450 Kbytes for 20 h from a fixed location, and downloading of an image file of size 180 Kbytes on a moving handheld PC at a speed of 100 km/h [20].

The handheld PC used was a Compaq iPAQ 3870 equipped with the GSM/GPRS expansion pack modem, whereas the laptop PC was an IBM Think Pad with a Globe Trotter high-speed GPRS wireless PCMCIA modem card. The laptop PC was also used with the Ericsson R520 mobile phone serving as a modem that allowed the Ericsson TEMS GSM/GPRS monitoring software to be used for field measurements.

The results presented in this study were carried out using the Compaq iPAQ 3870 handheld PC with the medical images and videos varying in size between 10 Kbytes to 2 Mbytes. Fig. 4 illustrates the comparison of GSM and GPRS for both SMTP and FTP protocols. The throughput for GPRS FTP varied between 30 and 35 kbps, whereas for the GPRS SMTP varied between 13 and 19 kbps. The throughput performance for GSM for both SMTP and FTP varied between 5 and 10 kbps. It is clearly shown that for FTP, the throughput performance of the GPRS is approximately triple to that of the GSM, whereas for SMTP the GPRS performance is 1.5 times to four times to that of GSM.

The analysis with the UMTS standard was also conducted at a later stage when the standard was just becoming available in Cyprus.

Fig. 5 illustrates the FTP download timing for varying size of image files carried out from a fixed point using (a) GPRS and (b) UMTS. As expected, the download timing is increasing proportionally with the increase in the size of the file. It is seen that the download speed for UMTS is almost ten times less than the speed for GPRS. The corresponding download speeds for the above experiment are shown in Fig. 6 for that specific time and point.

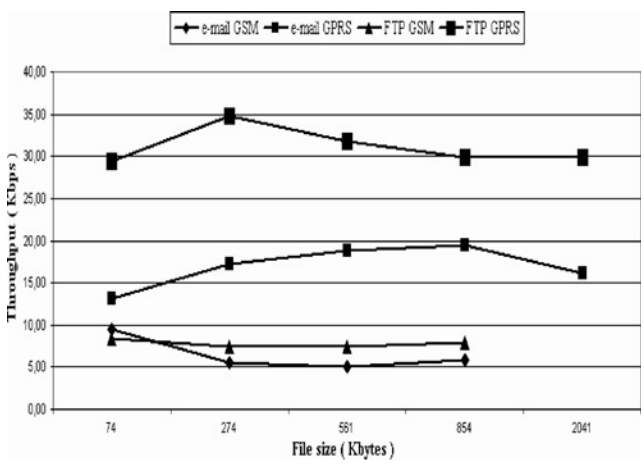

Figure 4 *Comparison of SMPT and FTP protocols over GSM and GPRS*

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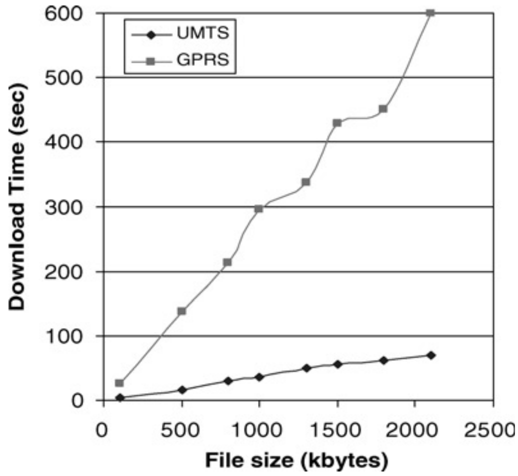

Figure 5 *Downloading timing for files of varying size using FTP over GPRS and UMTS*

Fig. 7 illustrates the repeated downloading of a 450 Kbytes video clip file from a fixed location over a period of 20 h. Speeds in the range of 30 kbps for GPRS and 250 Kbps for UMTS were achieved.

The download speed against distance in the case of a mobile station (i.e. the case for an ambulance) travelling in a highway at 100 km/h, downloading repeatedly a 180 Kbytes image file using FTP over GPRS is given in Fig. 8. The performance of the system for a significant length of the journey was very satisfactory, with throughput values in the range of 30–32 kbps. However, there were segments of the journey both in the normal and the return journeys where poor performance was recorded, with data transfer rates in the range of 7–11 kbps. In the region of 30 Km in the normal journey there were very bad weather conditions, which must have affected negatively the performance of the wireless network.

The experiments carried out showed that the GPRS and UMTS systems can be used successfully for the transmission

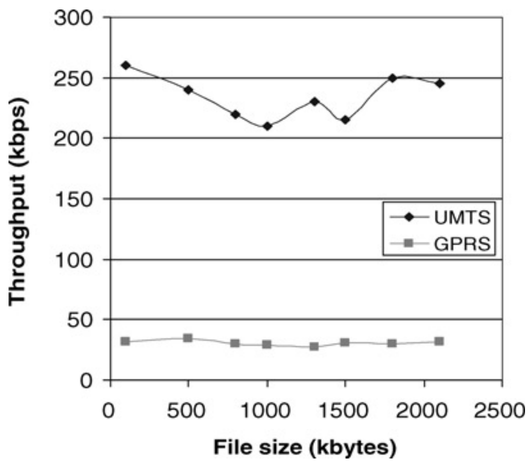

Figure 6 *Downloading speeds for varying file size using FTP over GPRS and UMTS*

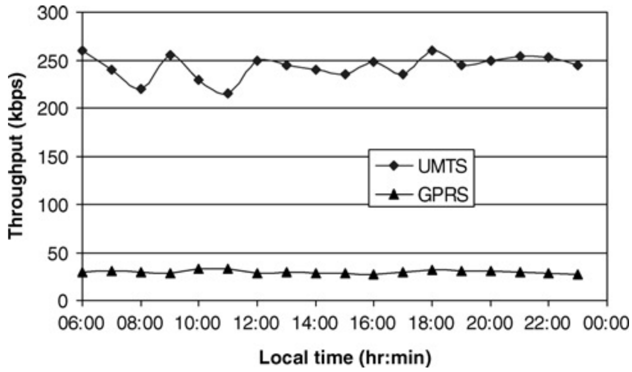

Figure 7 *Repeated downloading of a 450 Kbytes video clip over a period of 20 h using FTP over GPRS*

of medical images and video. The results showed clearly that the method of using FTP over GPRS was by far superior to Email. In the above experiments, a practical evaluation of the performance of the GSM, GPRS and UMTS systems in the transmission/reception of X-ray images and video in emergency orthopaedics cases was carried out.

The performance of UMTS is superior to that of GPRS that of course is superior to that of GSM. The data transfer rates normally achieved with UMTS were in the range of 250 kbps and for GPRS were in the range of 32 kbps, which is what was expected since the downlink bit rate for a 4 + 1 phone connection was between 5 and 40 kbps [20].

The download time for typical X-ray images, of file size 200 Kbytes, to the mobile device was in the region of 60 s for GPRS connection and 6–7 s for UMTS.

The system was also used in an emergency scenario where a prompt second opinion was requested remotely from the orthopaedics surgeon in the case of a serious operation. In this case, the doctors in the operating theatre transmitted X-ray images and a video clip to the mobile station via the ISP server, and then the X-ray images were retransmitted

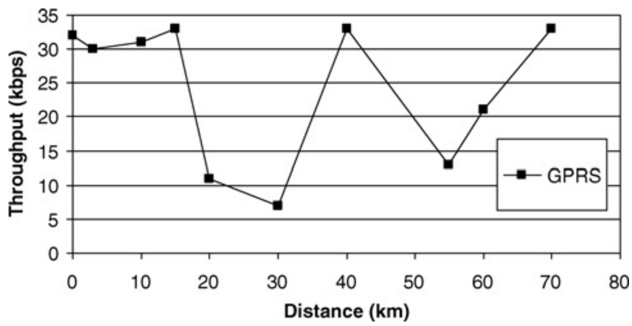

Figure 8 *Download speed against distance in the case of a mobile station travelling at 100 Km/h when downloading repeatedly a 180 Kbyte image file using FTP over GPRS*

back including the surgeon's notes/instructions as well as text and/or voice files. The whole teleconsultation scenario was carried out in <5 min. The performance of the system was also evaluated in the case of a moving station (simulating the ambulance) for the downloading of an X-ray image with GPRS speeds reaching 32 kbps for the biggest part of the journey.

4.2 Quality assessment by experts (mean opinion score)

The 24 X-rays in Table 1 were used for the quality assessment by all ten expert doctors. Each doctor was at first studying the original X-ray that no matter how good qualitywise it was considered as reference with maximum grade 5. Then each doctor was presented the same X-ray on a PC in digital format (compressed and uncompressed without the expert knowing which was which).

The original and the received images from the full system were presented at random to the orthopedics physicians, who could hardly differentiate the quality between them and were asked to assess their quality in a scale 1–5 corresponding to low-and high-subjective visual perception criteria. These images were obtained with the GPRS mobile standard as this standard was widely available in Cyprus during the field trials for testing the system. Five was given to an image with the best visual perception. Almost all images

Table 3 Comparison of scores for direct and tele-diagnosis of X-ray images (based on GPRS)

X-ray	Doc 1	Doc 2	Doc 3	Doc 4	Doc 5	Doc 6	Doc 7	Doc 8	Doc 9	Doc 10
1	5	5	5	5	5	4	4	5	4	5
2	5	5	5	5	5	5	5	5	5	4
3	5	5	5	5	5	5	5	5	5	5
4	4	5	5	5	4	5	4	5	5	4
5	5	5	5	5	5	5	5	5	5	5
6	5	5	5	5	4	4	5	5	5	5
7	5	5	5	5	5	5	5	5	5	5
8	5	5	5	5	5	5	4	5	5	5
9	5	5	4	4	5	5	4	5	5	5
10	5	5	5	4	5	5	5	4	5	5
11	5	5	5	5	4	5	5	5	5	5
12	4	4	4	4	5	5	5	5	4	4
13	5	5	5	5	5	5	5	5	4	5
14	4	4	4	4	5	5	5	5	5	4
15	4	4	4	5	5	5	5	5	5	4
16	5	5	5	5	5	4	5	5	5	5
17	5	5	5	5	5	5	5	4	5	5
18	5	5	5	5	5	5	4	5	5	5
19	5	5	5	5	4	5	5	5	5	5
20	5	5	5	5	5	5	5	5	5	5
21	5	5	5	5	4	5	5	4	5	5
22	5	5	5	5	5	5	4	5	4	5
23	5	5	4	4	5	5	5	5	4	5
24	5	5	5	5	5	5	5	5	5	5
MEAN	4.8	4.9	4.8	4.8	4.8	4.9	4.8	4.9	4.8	4.8
STD	0.4	0.3	0.4	0.4	0.4	0.3	0.4	0.3	0.4	0.4

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were marked by doctors with the maximum grade 5. The experts were allowed to give equal scores to more than one image in each case. The primary interest of the experts was to investigate whether the pathological condition shown on the original X-ray was exactly recognisable on the digitised image as in the original X-ray. The ten experts involved in the study rated the quality of the medical images as very satisfactory.

Table 3 shows a comparison between the score given by doctors to the clarity of X-rays when studied directly and when studied after processed through the telemedicine system. The mean score was between 4.8 and 4.9, with 5 being the maximum score, which shows that all doctors were satisfied with the quality of the compressed images.

Table 4 shows a comparison of the use of the ETOPS to the present practice with regard to the response time of doctors in handling the various incidents. Doctors can complete their communication for any of the six scenarios using ETOPS in a few minutes. In cases wherein that doctors were not using this system, the corresponding time was unpredictable because depending on the scenario. Thus many factors were involved that may have resulted in a delayed or incomplete communication (see last column of Table 4).

The following scenario was considered in the study: X-ray images and/or video clips of orthopedics cases captured at the accident and emergency department or the operating theatre of the hospital were uploaded to the server of the internet service provider. Fig. 9 shows typical X-ray images.

The expert, who at that time is driving in his car, is informed about the availability of the medical images to be assessed via SMS and voice call on his mobile as well as by Email. The expert is then connected to the server via GSM/GPRS/UMTS modem installed in his laptop or handheld PC the images are downloaded and then evaluated on the screen of the mobile station. This information is then communicated with the accident and emergency department via SMS, voice or Email giving his comments or instructions. In some cases, he may as well decide to add part of his instructions on the X-ray image received and then send them to his colleagues via the ISP server. Also, in some cases when an orthopaedics patient is driven by an ambulance to the hospital, a photograph of the trauma may be very helpful to be received (via wireless channels) by the doctors at the hospital since they may

Figure 9 *Sample of X-ray images transmitted (X-rays 11D and 17D of Table 1)*

Table 4 Speed of response of orthopaedics doctors when using the system (based on GPRS) compared to their speed of response under the present practice

No.	Scenarios of communication	time needed for a second opinion using System	without using system
1	communication of a doctor in a Rural Sanitary Centre and Expert Orthopaedics doctor in a Central hospital	3–5 min	15 min–3 h
2	communication of expert doctors (while being in the same hospital)	3–5 min	20–30 min
3	communication of expert doctors (independently from where they are)	depends on whether expert is available and/or whether he considers the situation to be urgent or not	depends on available means of transportation data (e.g. courier or post office)
4	communication of orthopaedic Surgeon from the operating theatre with an expert doctor	immediate	impossible
5	communication of paramedics in the ambulance with an orthopaedics doctor in a hospital	3–5 min	cannot have any opinion from expert
6	communication regarding possible need of patient's transportation from hospital to hospital	3–5 min	cannot have any opinion from expert

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draw certain preliminary conclusions regarding the state of the patient.

5 Conclusions

This paper presented a design, implementation and evaluation of an ETOPS employing wireless communication technologies. A prototype system has been designed and the system performance was evaluated using images (JPEG 2000 compression was employed) from two main hospitals in Cyprus. The picture quality was analysed using standard metric and opinions from the doctors in the hospital. Also, GSM, GPRS and UMTS wireless technologies have been investigated using the prototype and the UMTS performed well under practical conditions. It was shown that the download speed for UMTS was ten times faster that the speed for GPRS. It was also clearly shown that for FTP, the throughput performance of the GPRS is approximately triple to that of the GSM, whereas for SMTP the GPRS performance is 1.5 to 4 times to that of GSM for this prototype system.

Future work will focus in the provision of wireless telemedicine support system covering the needs of all hospitals of the country. The system will focus primarily in emergency services covering the accident and emergency department as well as the ambulance services. Moreover, the UMTS system that now covers most areas of the country will greatly leverage telemedicine services, thus enabling the offering of better services to the citizen.

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7 Appendix

The following measures that are easy to compute and have clear physical meaning, were computed

7.1 Normalised mean square error (MSE)

The mean square error (MSE) measures the quality change between the original and processed image in an $M \times N$ window 0

$$\mathrm{MSE} = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\frac{g_{i,j} - f_{i,j}}{\mathrm{lp}g_{i,j}}\right)^2 \tag{1}$$

where $\mathrm{lp}g_{i,j}$, is the low-pass filtered images of the original image, $g_{i,j}$ and $f_{i,j}$ is the compressed image. For the case that, $\mathrm{lp}g_{i,j}$, is equal to zero, its value is replaced with the smallest grey level value in the image. The MSE has been widely used to quantify image quality and when is used alone, it does not correlate strongly enough with perceptual quality. It should be used therefore together with other quality metrics and visual perception 0, 0, 0.

7.2 Normalised root mean square error (RMSE)

The root mean square error (RMSE) is the square root of the squared error averaged over an $M \times N$ array [12, 15]

$$\mathrm{RMSE} = \sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\frac{g_{i,j} - f_{i,j}}{\mathrm{lp}g_{i,j}}\right)^2} \tag{2}$$

The popularity of RMSE arises mostly from the fact that is in general the best approximation of the standard error.

7.3 Normalised error summation in the form of the Minkowski metric (Err)

The Err is the norm of the dissimilarity between the original and the processed images [12, 13, 16]

$$\mathrm{Err} = \left(\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left|\frac{g_{i,j} - f_{i,j}}{\mathrm{lp}g_{i,j}}\right|^{\beta}\right)^{1/\beta} \tag{3}$$

computed for $\beta = 3$ (Err_3) and $\beta = 4$ (Err_4). For $\beta = 2$, the RMSE, is computed as in (2), whereas for $\beta = 1$, the absolute difference, and for $\beta = \infty$ the maximum difference measure.

7.4 Normalised geometric average error (GAE)

It is a measure, which shows if the transformed image is very bad [12, 19], and it is used to replace or complete RMSE. It is positive only if every pixel value is different between the original and the transformed image. The geometric average error (GAE), is approaching zero, if there is a very good transformation (small differences) between the original and the transformed image, and high vice versa. This measure is also used for tele-ultrasound, when transmitting ultrasound images and is defined as

$$\mathrm{GAE} = \left(\prod_{i=1}^{N}\prod_{j=1}^{M}\sqrt{\frac{g_{i,j} - f_{i,j}}{\mathrm{lp}g_{i,j}}}\right)^{1/NM} \tag{4}$$

7.5 Normalised signal-to-noise ratio (SNR)

The signal-to-noise ratio (SNR) [27] is given by

$$\mathrm{SNR} = 10\,\log_{10}\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}((g_{i,j}^2 + f_{i,j}^2)/\mathrm{lp}g_{i,j})}{\sum_{i=1}^{M}\sum_{j=1}^{N}((g_{i,j} - f_{i,j})/\mathrm{lp}g_{i,j})^2} \tag{5}$$

The SNR, RMSE and Err, prove to be very sensitive tests for image degradation, but they are completely non-specific. Any small change, in image noise, filtering, and transmitting preferences would cause an increase of the above measures.

7.6 Normalised peak signal-to noise ratio (PSNR)

The peak signal-to noise ratio (PSNR) [12, 27] is computed by

$$\mathrm{PSNR} = -10\,\log_{10}\frac{\mathrm{MSE}}{s^2} \tag{6}$$

where s is the maximum intensity in the original image. PSNR is higher for a better transformed image and lower for a poorly transformed image. It measures image fidelity, that is, how closely the transformed image resembles the original image.

7.7 Mathematically defined universal quality index (Q)

This matrix models any distortion as a combination of three different factors [21], which are as follows: loss of correlation, luminance distortion, and contrast distortion and is derived as

$$Q = \frac{\sigma_{gf}}{\sigma_f \sigma_g} \frac{2\bar{f}\bar{g}}{(\bar{f})^2 + (\bar{g})^2} \frac{2\sigma_f \sigma_g}{\sigma_f^2 + \sigma_g^2} \quad -1 < Q < 1 \qquad (7)$$

where $\bar{g}$ and $\bar{f}$ represent the mean of the original and transformed image values, with their standard deviations, σ_g, and σ_f, of the original and transformed values of the analysis window, and σ_{gf}, represents the covariance between the original and transformed images. Q is computed for a sliding window of size 8×8 without overlapping. Its highest value is 1 if $g_{i,j} = f_{i,j}$, while its lowest value is –1 if $f_{i,j} = 2\bar{g} - g_{i,j}$.

7.8 Structural similarity INndex (SSIN)

The Structural Similarity INndex (SSIN) between two images, which is a generalisation of (7) is given by

$$\text{SSIN} = \frac{(2\bar{g}\bar{f} + c_1)(2\sigma_{gf} + c_2)}{(\bar{g}^2 + \bar{f}^2 + c_1)(\sigma_g^2 + \sigma_f^2 + c_2)} \quad -1 < Q < 1 \quad (8)$$

where $c_1 = 0.01\text{dr}$, and $c_2 = 0.03\text{dr}$, with $\text{dr} = 255$, representing the dynamic range of the ultrasound images. The range of values for the SSIN lies between –1 and +1. Bad similarity between the original and transformed images corresponds to –1 and good similarity corresponds to +1. It is computed, similarly to the Q measure, for a sliding window of size 8×8 without overlapping.

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