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Wireless Telemedicine Systems: An Overview

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Abstract

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. The objective of this paper is to provide a snapshot of the applications of wireless telemedicine systems. A brief review of the spectrum of these applications and the potential benefits of these efforts will be presented, followed by successful case studies in electronic patient record, emergency telemedicine, teleradiology, and home monitoring. It is anticipated that the progress carried out in these efforts and the potential benefits of emerging mobile technologies will trigger the development of more applications, thus enabling the offering of a better service to the citizen.

Keywords: Telemedicine; land mobile radio cellular systems; land mobile radio data communication; medical services; GSM; information technology; communication systems; radiography; emergency services

1. Introduction

Telemedicine can be defined as the delivery of health care and the sharing of medical knowledge over a distance, using telecommunication means. It aims at providing expert-based medical care to any place where health care is needed. Telemedicine, as a concept, was introduced about 30 years ago, when telephone and fax machines were the first telecommunication means used. In recent years, several telemedicine applications have been successfully implemented over wired communication technologies like POTS (plain old telephone system) and ISDN (integrated services digital network). However, nowadays, modern wireless telecommunication means, such as the GSM (Groupe Speciale Mobile – Global System for Mobile Communications), GPRS (General Packet Radio Service), and the forthcoming UMTS (Universal Mobile Telecommunications Systems) mobile telephony standards, as well as satellite communications, allow the operation of wireless telemedicine systems, freeing the medical personnel and/or the subject monitored from being bound to fixed locations [1-3]. The objective of this paper is to present a review of wireless health systems.

Telemedicine applications, including those based on wireless technologies, span the areas of emergency health care: telecardiology, teleradiology, telepathology, teledermatology, teleophtlalmology, teleoncology, and telepsychiatry. In addition, health telematics applications, enabling the availability of prompt and expert medical care, have been exploited for the provision of health-care services at understaffed areas, such as rural health centers, ambulance vehicles, ships, trains, and airplanes, as well as for home monitoring [4-10].

The structure of this paper is as follows. In Section 2, wireless technologies are introduced, followed by Section 3, on the transmission of digital images and video. In Section 4, an overview of wireless telemedicine systems, documented through published conference or journal papers, is given. This is followed by a brief summary of completed and ongoing European Union (EU)-funded projects, in Section 5. Selected case studies of these systems are presented in Section 6, followed by Section 7 with concluding remarks. A shorter version of this paper was published in [11].

2. Wireless Technologies

In this section, we briefly describe the main wireless technologies that have been used in wireless telemedicine systems: GSM, satellite, and wireless local-area network (WLAN). These systems are summarized in Table 1. GSM is a system currently in use, and is the second-generation (2G) of mobile-communication networks. When it is in the standard mode of operation, it provides data-transfer speeds of up to 9.6 kbps. Through the years, a new technique was introduced in the GSM standard, called High Speed Circuit Switched Data (HSCSD). This technology makes it possible to use several time slots simultaneously when sending or receiving data, so the user can increase the data transmission rate to 14.4 kbps (an increase of 50%), or even triple it to 43.3 kbps [12].

Their is an evolution of mobile telecommunication systems from 2G to 2.5G (iDEN, 64 kbps; GPRS, 171 kbps; EDGE, Enhanced Data rate for GSM Evolution, 384 kbps) and, subsequently to 3G (W-CDMA, wideband code-division multiple access; CDMA2000, TD-CDMA) systems. This will facilitate the provision of faster data-transfer rates, thus enabling the development of telemedicine systems that require high-data-transfer rates, and that are currently only feasible on wired communication networks [12]. Satellite systems are able to provide a variety of data-transfer rates, starting from 2.4 kbps, and moving to high-speed data rates of up to 2 × 64 kbps, and even more. Satellite links also have the advantage of operating all over the world [13].

WLAN is a flexible data-communications system, implemented as an extension to or as an alternative for a wired LAN. Using radio frequency technology, WLANs transmit and receive data over the air, minimizing the need for wired connections. Thus, WLANs combine data connectivity with user mobility. They are becoming very popular in a number of vertical markets, including healthcare, retail, manufacturing, warehousing, and academia. These industries have profited from the productivity gains of using hand-held terminals and notebook computers to transmit real-time information to centralized hosts for processing. Today, wireless LANs are becoming more widely recognized as a general-purpose connectivity alternative for a broad range of applications. We fore-

Table 1. The main wireless communication networks/standards.

Type	Sub-type	Frequency Band	Data Transfer Rates
GSM	GSM-900	900 MHz	9.6 – 43.3 kbps
	GSM-1800	1800 MHz	9.6 – 43.3 kbps
	GSM-1900	1900 MHz	9.6 – 43.3 kbps
GPRS	GPRS	900/1800/1900 MHz	171.2 kbps
Wireless LAN	IEEE 802.11a	5 GHz	20 Mbps
	IEEE 802.11b	2.4 GHz	11 Mbps
	Hiperlan1	5 GHz	20 Mbps
	Hiperlan2	5 GHz	54 Mbps
	Bluetooth	2.4 GHz	723.2 Mbps
Satellite	ICO	C, S band	2.4 kbps
	Globalstar	L, S , C band	7.2 kbps
	Iridium	L, Ka band	2.4 kbps
	Cyberstar	Ku, Ka band	400 kbps – 30 Mbps
	Celestri	Ka band and 40-50 GHz	155 Mbps
	Teledesic	Ka band	16 kbps – 64 Mbps
	Skybridge	Ku band	16 kbps – 2 Mbps

see that this technology will penetrate the health sector in the near future.

3. Transmission of Digital Images and Video

3.1 Transmission of Digital Images

The use of digital imaging in medicine has benefited from the formation of the Digital Imaging and Communications in Medicine (DICOM) committee [14]. The committee was formed in 1983, by the American college of Radiology (ACR) and the National Equipment Manufacturers Association (NEMA). For still images, DICOM has adopted various JPEG variants, such as lossless JPEG and JPEG-LS [15], and it is expected to adopt JPEG 2000 [16]. For digital video, the DICOM committee may adopt the MPEG-2 standard [17].

There are essentially no theoretical bandwidth requirements for transmitting medical images. In effect, lack of bandwidth can be compensated for by longer transmission times. Yet, high-quality medical images, such as a single chest radiograph, may require from 40 to 50 MB. In practice, it is desirable to at least be able to transmit medical images during a single patient visit, so as to avoid a follow-up visit.

Due to the diagnostic use of medical images, medical image-compression techniques have primarily focused on lossless methods, where the image can be reconstructed exactly from its compressed format [18-19]. Unfortunately, lossless methods can only provide limited compression ratios, usually ranging between 2 and 3.7 [20]. With lossy compression methods, the original image is only approximately reconstructed from its compressed format. Hence, adoption of lossy image-compression techniques requires the careful evaluation of the effect of compression on diagnostic performance [21]. In general, optimum performance requires the study of the impact of compression on different diagnostic situations. Clearly, though, the background of most images is of no diagnostic value. Hence, "region of interest" (ROI) techniques can be used to avoid compression of the background, and thus provide substantial improvements in compression ratios [22]. For example, where the region of interest covers about 20% of the entire image, average compression ratios of about 15.1 have been reported using JPEG-LS, while an average compression ratio of only 2.58 is possible using the entire image as the region of interest [22].

Another solution is to provide a simple perceptual test, where the participants are asked to identify the original image in a set that is composed of compressed images and the original image. Clearly, if the original image cannot be identified, then the compressed images that are confused as original will also not impact the diagnosis [22]. This technique leads to near-lossless techniques, where the uncompressed image differs from the original in only a small number of levels (± 1, ± 2, out of a possible 4096 levels). For comparison, JPEG-LS in lossless mode provides for an average compression ratio of 2.58, which improves to 3.83 in the near-lossless mode (± 1 levels) [22]. In addition, for a region of interest that covers 20% of the image region, the average compression ratio improves from 15.1 to 22.0 [22].

3.2 Transmission of Digital Video

As mentioned earlier, the DICOM committee has not yet adopted any standard for digital video compression. The adoption of MPEG-2 is possible, but this is limited by the MPEG-2 requirement for the constant-delay method for frame synchronization [17, 23]. The constant-delay requirement is not supported by ATM (asynchronous transfer mode) networks, making it difficult to deliver real-time MPEG-2 video over ATM [23]. On the other hand, the transmission of offline video is still possible.

It is important to distinguish among the requirements for real-time video transmission, offline video transmission, medical video and audio for diagnostic applications, and non-diagnostic video and audio. Real-time video transmission for diagnostic applications is clearly the most demanding. Offline video transmission is essentially limited by the requirement to provide patient-doctor interaction. Real-time diagnostic audio applications include the transmission of stethoscope audio, or the transmission of the audio stream that accompanies the diagnostic video. Good-quality diagnostic audio at 38-128 kbps using Dolby AC-2 has been achieved, while MPEG-1 Layer 2 audio (32-256 kbps) or Dolby AC-3 (96-768 kbps) may also be used [23]. For non-diagnostic applications, such as teleconferencing, H.261 (64 kbps - 1.92 Mbps) and H.263 (15-64 kbps) may be acceptable [23]. A typical application will require a diagnostic audio and video bit stream, in addition to a standard teleconferencing bit stream.

Due to the high bandwidth requirements and the frame-synchronization problem, successful methods for real-time diagnostic video transmission will most likely require the adoption of the MPEG-4 standard [23-25]. The frame-synchronization problem is alleviated in MPEG-4 via the use of timestamps on each frame [24-25]. A possible method for achieving acceptable video compression for diagnostic purposes may be through the use of object-based encoding and decoding. In object-based encoding and decoding, different bit rates are allocated to different parts of the digital video, according to the level of diagnostic importance. The advantage of this approach is that it can significantly reduce the required bandwidth, while maintaining high-quality video images of the regions of diagnostic interest. As an example, it is important to note that most of the bandwidth in digital-video transmission is spent on tracking moving objects in video images. Clearly, if there is no motion between successive images, then high-quality video can be achieved by simply encoding the small differences between video frames. This would be automatically detected in all video-compression standards. Furthermore, in many clinical applications – such as in personal injury – it is clearly the case that the stationary part of the video is of significant importance, as opposed to moving objects in the background. A disadvantage of object-based coding is that it is not always clear which part of the video is of diagnostic importance. This obstacle can be overcome by using interactive video, where the user can interactively select a region of interest.

4. Wireless Telemedicine Systems

The INSPEC and MEDLINE databases were searched with the following keywords: telemedicine and mobile, telemedicine and GSM, telemedicine and GPRS. The number of papers (including both conference and journal papers) published under these categories in the years 1979 to 2001 was 132. Out of these reports of wireless telemedicine systems published in the literature, a total of 35 selected applications are briefly summarized in Table 2. These systems cover a significant component of the whole spectrum of health telematics applications. They are grouped in Table 2 primarily under the wireless technologies of GSM, satellite, radio, and wireless LAN. Under each of these technologies, the systems are grouped into the areas of emergency healthcare, telecardiology, teleradiology, telepsychology, teleopthalmology, and remote monitoring (including monitoring at rural health centers, home monitoring, and subject monitoring at distant or isolated locations). In addition, in Table 2 the data transmitted are coded under the following columns: "Signals" for bio-signals, "IMG" for medical imaging or video, "EPR" for electronic patient record, and

Table 2a. Selected applications of wireless telemedicine systems: GSM.

Authors	Year	Area	Data Transmitted				Comments
			Signals[1]	IMG[2]	EPR[3]	AIV[4]	
Schôchinger et al. [26]	99	Emergency					Early hospital admission
Karlsten et al. [27]	00	Emergency	ECG				Ambulance triage support
Yan Xiao et al. [28]	00	Emergency	BIO			V	Ambulance neurological examination support
Anantharaman et al. [29]	01	Emergency	ECG				Pre-hospital support
Rodrvguez et al. [30]	01	Emergency	ECG				Cardiac arrest treatment
Istepanian et al. [31, 32]	01	Emergency	ECG				Wavelet ECG compression
Pavlopoulos et al. [4, 5]	01	Emergency	ECG,BP, Temp, S_PO_2,CO_2			A, I	Portable teleconsultation medical device
Reifart et al. [33]	97	Telecardiology	ECG				12- lead ECG transmission
Istepanian et al. [34]	99	Telecardiology	ECG, PPG				IS-54&GSM cellular telephone standards
Scalvini et al. [35]	00	Telecardiology	ECG				Massive evaluation of an emergency ECG service
Reponen et al. [36]	00	Teleradiology		CT			PDA based CT teleconsultation
Schulze et al. [37]	00	Telepsychology					Support of patients with brain disturbances
Yogesan et al. [38]	00	Teleophthalmology		ODI			Glaucoma screening
Hofman et al. [39]	96	Remote monitoring	BIO				General purpose telemedicine system
Butera et al. [40]	97	Remote monitoring					Support in disaster situations
Bukhers et al. [41]	97	Remote monitoring			•		Real time patient-soldier battlefield monitoring
Woodward et al. [42]	01	Remote monitoring	ECG				Mobile telephony ECG transmission

Table 2b. Selected applications of wireless telemedicine systems: Satellite.

Authors	Year	Area	Data Transmitted				Comments
			Signals[1]	IMG[2]	EPR[3]	AIV[4]	
Murakami et al. [43]	94	Emergency	ECG, BP			A, I	Telemedicine support in aircraft & ship
Kyriacou et al.[4]	01	Emergency, Remote monitoring	ECG,BP			A, I	Portable teleconsultation medical device
Stewart et al. [44]	99	Teleradiology		US		V	Ultra Sound image compression
Takizawa et al. [45]	01	Teleradiology		CT			Spiral CT mobile van (lung cancer screening)
Yogesan et al. [38]	00	Teleophthalmology		ODI			Glaucoma screening
Otto et al.[46]	97	Remote monitoring	ECG, BP			V	Disaster situations
Anogianakis et al. [47]	97	Remote monitoring			•		Maritime telemedicine
Samiotakis et al. [48]	97	Remote monitoring			•		Basic telemedicine services
Navein et al. [49]	98	Remote monitoring				V	US army portable telemedicine system
Lamminen et al. [50]	99	Remote monitoring				A	Travelers and educators support
Pitsillides et al. [10]	99	Remote monitoring			•	V	Monitoring of cancer patients
Harnett et al. [51]	00	Remote monitoring					climbers' hypoxia monitoring

Table 2c. Selected applications of wireless telemedicine systems: Radio.

Authors	Year	Area	Data Transmitted				Comments
			Signals[1]	IMG[2]	EPR[3]	AIV[4]	
Schimizu et al. [52]	99	Emergency	ECG, BP			V	Telemedicine support in aircraft & ship
Fuchs et al. [53]	79	Remote monitoring				V	Telemedicine support in isolated areas
WLAN							
Banitsas et al. [54]		Emergency			•	A,V	A&E ward mobile trolley
Reponen et al. [57]	00	Teleradiology		CT	•		EPR data base teleconsultation
Finkelstein et al. [58]	98	Remote monitoring	FVC				Home monitoring of asthma patients
Goussal et al. [59]	97	Remote monitoring					Telemedicine support in isolated areas

[1]Signals: ECG: Electrocardiograph, BIO: Biosignals, BP: Blood Pressure, Temp: Temperature, SpO2: Oxygen saturation, CO2: Carbon dioxide measurement, PPG: PhotoPlythiSmography, FVC: Forced Vital Capacity

[2]IMG: Medical imaging, US: Ultrasound, CT: Computer Tomography, ODI: Optical Disc Image

[3]EPR: Electronic Patient Record

[4]AIV: Teleconferencing mode, A: Audio communication, I: Image communication (non-medical), V: Video communication (non-medical)

Table 3. EU-funded wireless telemedicine projects under the Third (1990-1994) and Four (1994-1998) Framework Programmes.

Project/Program/Duration/Total Cost	Area	Comm. Technologies[1]	Data Transmitted				P/C[6]
			Signals[2]	IMG[3]	EPR[4]	AIV[5]	
Multimedia portable digital assistant (MULTIPORT)/ACTS/ 1995-97(42 months)/ 6.47 MECU	Hospital Rural areas	WLAN, GSM			•		7/4
Mobile Medical Data (MOMEDA)/ Telematics/ 98-00(24 m)/ 1.5 MECU	Hospital Rural areas	GSM		MRI X-Ray	•		11/3
Wireless ATM network demonstrator (WAND)/ACTS/95-98 (36 m)/12.84 MECU	Rural areas	WATM				V	13/7
System for advanced *mobile* broadband applications (SAMBA)/ACTS/96-99(32m)/13.29 MECU	Rural areas	WATM				V	15/6
Mobile unit for health care provision via telematics support (AMBULANCE)/Telematics/96-97(24 m)/2.45 MECU	Emergency Rural areas	GSM	ECG, SPO2 BP, Temp			I	11/4
Mobile Experimental Broadband Interconnection Using Satellites (MOEBIUS)/Race 2/ 92-95(48 m)/	Emergency	SATH				V	12/6
European telemedicine for medical assistance (ET-ASSIST)/Telematics/96-99(36m)/3.85 MECU	Emergency	SAT, GSM			•		8/5
An Integrated Portable Device for Emergency Telemedicine (Emergency-112)/Telematics/98-00(24m)/0.9 MECU	Emergency Rural areas Remote monit.	SAT, GSM	ECG, SPO2 BP, Temp			I	9/4

[1]Communication Technologies: GSM: Global system for Mobile Communications, SAT: Satellite Communications, SATH: Satellite Communications (High speed data), WATM: Wireless ATM, WLAN: Wireless LAN. [2]Signals: ECG: Electrocardiograph, BIO: Biosignals, BP: Blood Pressure, Temp: Temperature, SpO2: Oxygen saturation, CO2: Carbon dioxide measurement.
[3]IMG: Medical imaging, MRI: Magnetic resonance image, X-ray: X-ray images. [4]EPR: Electronic Patient Record.
[5]AIV: Teleconferencing mode, A: Audio communication, I: Image communication (non medical), V: Video communication (non medical).
[6]P/C: Partners/Countries involved.

"AIV" for audio (A), image (I), or video (V) teleconferencing. The last column of Table 2 gives some comments characterizing the system described.

The majority of these applications (17) used the GSM network, and the papers were published between the years 1999 and 2001. These applications covered the areas of emergency telemedicine (7), remote monitoring (4), and telecardiology (3). Satellite links were also used in many telemedicine applications (12). Most of these systems were used for remote monitoring (8), followed by emergency telematics (2) and telecardiology (2). Satellite systems have the advantage of worldwide coverage and offer a variety of data transfer speeds, even though satellite links have the disadvantage of high operating cost. A few analog radio telemedicine systems were developed for the support of aircraft and ships in isolated areas. Finally, WLAN technology is an emerging technology, already being applied for emergency telematics and teleradiology.

5. EU- Funded Projects in Wireless Telemedicine

The European Community has supported, and is currently supporting, wireless telemedicine projects under the following programs: (1) Third RTD Framework Programme 1990-1994, (2) Fourth RTD Framework Programme 1994-1998, and (3) Fifth RTD Framework Programme 1998-2002 [60].

Table 3 summarizes the projects funded under the Third and Fourth framework program, whereas Table 4 summarizes the ongoing projects under the Fifth framework program. Both tables are structured similarly. In Table 3, the first column gives the project name/program/duration/total cost and funding, the second column gives the area of application, and the third column gives the technology employed. The fourth column, "Data Transmitted," is structured similarly to Table 2 in that it is subdivided under "Signals," images, electronic patient records, and teleconferencing mode. The last column gives the number of partners and countries involved.

Table 3 shows that most of the projects carried out under the two programs in the time span 1990-1998 fall under the area of rural-area support (6), followed by projects for emergency telematics (4). These projects exploited mainly the GSM and satellite wireless technologies. Most of the ongoing projects (1998-2002) fall under the areas of hospital support (3) and remote monitoring (3) (see Table 4). These projects exploit Bluetooth, UMTS, and GPRS wireless technologies.

VI. Case Studies

In this section, case studies of successful wireless telemedicine systems in emergency health telematics, telecardiology, teleradiology, electronic patient record, and home monitoring are given.

5.1 Emergency Telemedicine: The Ambulance and Emergency-112 Projects [4]-[8]

The availability of prompt and expert medical care can meaningfully improve health-care services in understaffed rural or remote areas. The provision of effective emergency telemedicine and home-monitoring solutions is the major field of interest of the Ambulance HC1001 and Emergency-112 HC4027 projects, which were partially funded by the European Commission/DGXIII Telematics Application Programme. An overview of the concept of both projects is shown in Figure 1.

Table 4. Ongoing EU wireless telemedicine projects under the Fifth Framework Programme (1998-2002).

Project/Program/Duration/Total Cost	Area	Comm. Technologies[1]	Data Transmitted			P/C[5]
			Signals[2]	Img[3]	EPR[4]	
Mobile devices for healthcare applications (MOBI-DEV)/IST/01-03(30m)/3.27 MECU, 1.75 MECU	Hospital	Bluetooth, UMTS			•	11/5
Continuous Care (C-CARE)/IST/00-02(26m)/2.69 MECU 1.36 MECU	Hospital	MCN			•	12/4
Mobile Workflow Support and InformAtion distribution in hospitals via voice-opeRateD, wIreless-Networked HANDheld PCs (WARD-IN-HAND)/IST/00-02(27m)/3.24 MECU, 1.7 MECU	Hospital	MCN			•	7/5
Personal intelligent health mobile systems for *Telecare* and Tele-consultation (HEALTHMATE)/IST/01-03(30m)/2.85 MECU, 1.43 MECU	Emergency Rural areas	GPRS UMTS			•	7/3
Mobile Tele-echography Using An Ultra-light Robot (OTELO)/IST/01-04(30)/3.34 MECU, 1.81 MECU	Teleradiology	SAT GPRS		U/S		9/5
Enabling Best Practices For Oncology (BEPRO)/IST/01-02(18m)/1.47 MECU, 0.865 MECU	Teleoncology	MCN			•	10/5
Distance Information Technologies For Home Care (CHS)/IST/00-02(36m)/2.87 MECU, 1.78 MECU	Remote monitoring	MCN	Diabetes ECG			9/6
Enhanced Personal, Intelligent and *Mobile* system for Early Detection and Interpretation of Cardiological Syndromes (EPI-MEDICS)/IST/01-03(36m)/2.44 MECU, 1.36 MECU	Remote monitoring	MCN	ECG			8/3
Telematic Support for Patient Focused Distant Care (TELEMEDICARE)/IST/00-02(30m)/3.65 MECU, 1.88 MECU	Remote monitoring	MCN	ECG BP SpO2 temp			7/4
Re-organising The Logistic, Delivery And Dosing Of Drugs (PHARMA)/IST/01-02(24m)/3.98 MECU, 2.03 MECU	Drugs delivery	MCN				8/4

[1]Communication Technologies: MCN: Mobile Communication Network. [2]Signals: ECG: Electrocardiogram, BP: Blood Pressure, Diabetes: Signals concerning diabetics monitoring (Glucose etc.). [3]IMG: Medical imaging, U/S: Ultrasound images. [4]EPR: Electronic Patient Record. [5]P/C: Partners/Countries involved

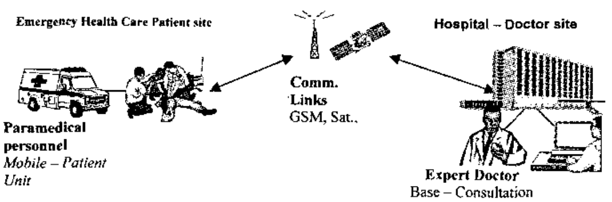

Figure 1. An overview of the Ambulance and Emergency-112 projects.

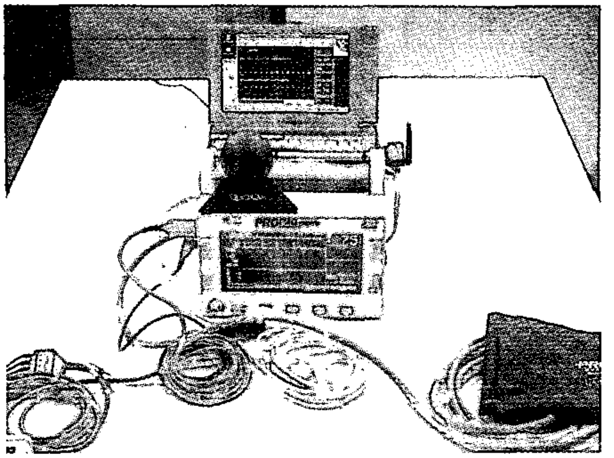

Figure 2. The portable version of the Emergency-112 system (from Emergency-112 Project [9], ©2000 Emergency-112 HC4027, used with permission).

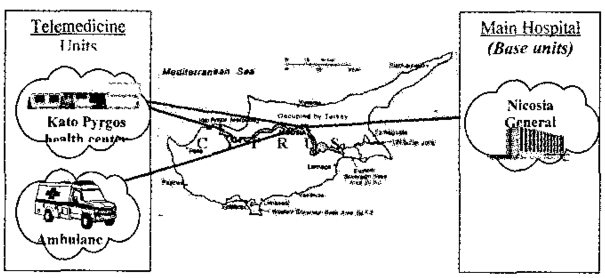

Figure 3. The Emergency-112 network infrastructure for the island of Cyprus.

The aim of the Ambulance [5] project was the development of a portable emergency telemedicine device, which supports real-time transmission of critical bio-signals, as well as still images of the patient, using the GSM link. This device can be used by paramedics or non-specialized personnel who handle emergency cases, in order to get directions from expert physicians. The system comprises two different modules: (1) the mobile unit, which is located in an ambulance vehicle near the patient; and (2) the consultation unit, which is located at the hospital site, and can be used by the experts in order to give directions. The system allows telediagnosis, long-distance support, and teleconsultation with mobile health-care providers by experts located at an emergency coordination center or a specialized hospital.

EMERGENCY-112 [6-8], which was the extension of the Ambulance project, aimed at the development of an integrated portable medical device for emergency telemedicine. The system enables the transmission of critical bio-signals (ECG, BP, HR, SpO_2, temperature), and still images of the patient, from the emergency site to an emergency call center. It thus enables physicians to direct pre-hospital care in a more efficient way, improving patients' outcome and reducing mortality. The system was designed to operate over several communication links, such as satellite, GSM, POTS, and ISDN. In Emergency-112, emphasis was given to maximizing the system's future potential application through the utilization of several communication links (both fixed and wireless), as well as through the increase of the overall system's usability, focusing on an advanced user interface and ergonomics. The system comprises two different modules. The first is the patient unit, which is the unit located near the patient (see Figure 2). This unit can operate automatically over several communication means, and has several operating features (depending on the case used). The second unit is the physician's unit, which is the unit located near the expert doctor. This unit can operate over several communication links (depending on the place where the expert doctor is located). The final system was used to provide emergency health care over several communication links (from ambulances, rural hospital centers or any other remotely located health center, and navigating ships), and for patient home monitoring. Emergency-112 has been used successfully in three European countries (Greece, Italy, and Cyprus) since 1998. The network infrastructure for the island of Cyprus is shown in Figure 3.

5.2 Diagnostic Accuracy of an ECG Telecardiology Service [61]

In this study, the diagnostic accuracy of a telecardiology service, employed in the daily activity of 150 general practitioners, was evaluated. Each practitioner was equipped with a 12-lead ECG portable electrocardiograph (Card-Guard 7100), which was connected to a mobile (GSM) or fixed (POTS) connection. At the consultation site, a specialized cardiologist was available, in order to give directions to the general practitioner. The system was tested for one year, in which 3456 calls took place. At the time of the ECG recording, 44% of patients were symptomatic. ECG teleconsultation satisfactorily supported all the problems for 2452 (71%) of the patients, whereas further diagnostic tests were requested for 862 (25%) of the patients. For 142 (4%) of the patients, referral to the emergency department was given. Cardiological diagnosis was confirmed in 95 (73%) of the patients, while anxiety or gastritis was presumed in 35 (27%) of the patients. In the group of patients ($n = 3314$) for whom the cardiologist solved the problem without referral to the emergency department, there were five patients who were admitted to the emergency department for myocardial ischemia in the 48 hours following the teleconsultation. The study concluded that the telecardiology service, when compared to emergency-department admission, showed a sensitivity of 95%, a specificity of 97.5%, and a diagnostic accuracy of 92.5%.

5.3 A Teleradiology System Using a Mobile CT Van and High-Speed Satellite Communication [45]

In this system, a mobile van houses a whole-body spiral computed-tomography (CT) scanner, and a second van houses the satellite communications equipment. This system was used for CT scanning, online two-way transfer of image data, and teleconferencing to a consultation center with various specialists. The system personnel consist of two drivers, a radiology technician who operates the CT scanner, and the telecommunications unit. The mobile CT van is 12 m long, and is equipped with a whole-body CT scanner, designed for lung-disease screening. In addition, the van houses a PC for CT data transmission, teleconferencing equipment, an image printer, a facsimile machine, and resuscitation equipment. The stationery diagnostic center is equipped with a Sun Sparc 1000 server, equipped with a 209 GB, RAID 7 disk array, and an image-observing station with two 21 in, 1728 × 2304 monochrome monitors, and a 1280 × 1600 color monitor. The mobile and stationary stations communicate at 155 Mbps in asynchronous transmission mode (ATM) via satellite or ISDN. The protocol used for image communication is DICOM 3.0, and, for online diagnosis to screen CT images, it takes 10 min for the transmission of 16.5 MB. The system was applied for the screening of 19117 residents in 29 districts of Japan. This resulted in the identification of 75 cases of early lung cancer, which were subsequently treated by partial pneumonectomy. In addition, the system was applied to providing medical services in rural areas, at sporting events, and for home monitoring. The usefulness of the proposed system is limited by the high initial cost for building the system (US$ 8,000,000), by the number of subjects scanned, as well as by the satellite-communications fee. These costs can be significantly lowered via the manufacture of 10 similar CT vans, doubling the number of subjects examined, and transmitting the images via the use of a multi-port format and in compressed format.

5.4 Electronic Patient Record: Mobile Medical Data (MOMEDA) [36, 55-57, 62]

Adequate, continuous information about patients during advanced medical procedures is a major factor in the patients' overall satisfaction. Moreover, patients, while hospitalized, need to continue their daily routine, or they at least need to be able to communicate through modern means (via e-mail or fax, for example) with the outside world. On the other hand, specialized physicians who are moving inside or outside the hospital need to have complete and continuous information about a patient's record, in order to be able to provide the best medical practice. These are the main issues addressed by the Momeda HC4015 telemedicine project [62], which was partially funded from the European Commission/DGXIII Telematics Application Programme. The system consisted of two modules, as illustrated in Figure 4: (1) the patient's information module, and (2) the doctor's information module.

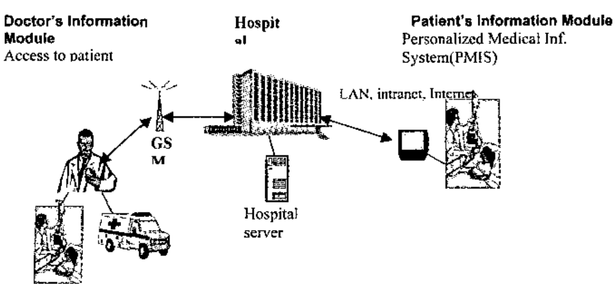

Figure 4. An overview of the Momeda project.

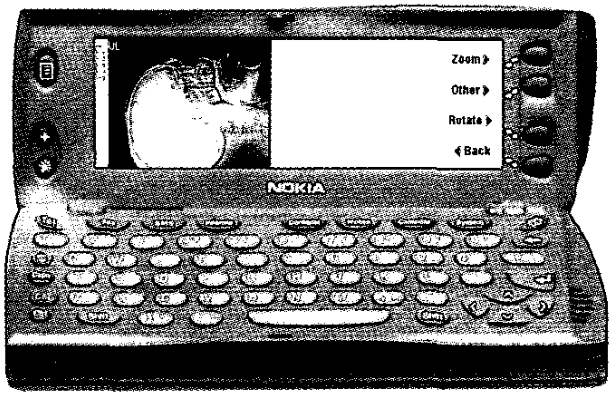

Figure 5. The doctor's handheld device, as shown on the *Momeda project Web site (from the Momeda web page [62],* ©1999 Momeda HC4015, used with permission).

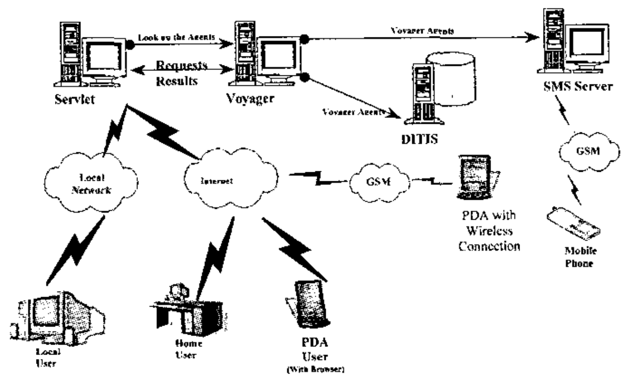

Figure 6. The DITIS network infrastructure for medical collaboration (from the DITIS Web page [9], ©1999 DITIS project, used with permission).

The main objective of the patient's information module was the development of a demonstration unit called the Personalized Medical System (PMIS) [55, 56]. This system allows access to customized disease-specific information from patients about their medical problem, the planned medical procedures, and what lifestyle they should have during hospitalization, and afterwards.

The main objective of the doctor's information module was the development of a demonstration unit that allows the consulting physician to access electronic patient records, using a hand-held companion device, connected to the GSM network [36, 57]. A module based on the Nokia Communicator 9110 was developed (see Figure 5) and tested through the project. The user of this module was able to connect to the hospital's main server, and to receive electronic records and medical images, such as MRIs. The project was successfully tested in three European countries (Finland, Italy, and Greece).

5.5 DITIS: Collaborative Virtual Medical Team for Home Healthcare of Cancer Patients [9, 10]

Complex and chronic illnesses, such as cancer, demand the use of specialized treatment protocols, administered and monitored by a coordinated team of professionals. Home-based care of chronic illnesses (e.g., cancer) by a team of professionals is often a necessity, due to the protracted length of the illness. In contrast, hospital-based treatment is limited, and is often demand-based for short periods of time. As it is not possible for the health-care team to be physically present with the patient at all times while the patient is undergoing treatment, a principal aim of the current project is to overcome this problem, through a network for medical collaboration called DITIS (ΔΙΤΗΣ in Greek, which stands for Network for Medical Collaboration) [9, 10]. DITIS is a system that supports virtual medical teams dealing with the home healthcare of cancer patients in Cyprus, and it is currently exploited at the European level. It aims to support the creation, management, and coordination of virtual medical teams for the continuous treatment of the patient at home, and, if needed, for periodic visits to places of specialized treatment and at home.

The design and development of the DITIS telecooperation system (the infrastructure of which is given in Figure 6) is based on Internet and GSM/WAP (wireless application protocol) connectivity. It includes four modules. The first module consists of *mobile agents*, e.g., IBM's *Aglets* workbench, Mitsubishi's *Concordia*, and *Voyager*, for the implementation of a flexible communication infrastructure for the support of mobile users. The mobile agents may be extended to offer intelligence and cooperation. The second module is a *Web-based database* for the storage and processing of the *Electronic Medical Record*. The third module is a *telecooperation system* for the sharing of information, team communication, and the coordination of team activities. The fourth module is an *adaptive intelligent interface* for database access from a variety of access units, such as mobile computing units with GSM Internet connectivity, and fixed units with Internet access supporting telecooperation.

6. Concluding Remarks

This paper has attempted to give a snapshot of completed, ongoing, and emerging applications of wireless information-technology applications in health systems. Wireless telemedicine technologies – linked with emerging technological trends such as pervasive computing (enabling seamless human-computer interactions with multimedia databases, "smart" cards), intelligent-agent technology, electronic-commerce applications in the healthcare sector, high-bandwidth Web, and citizen-centered services – provide promising solutions for forthcoming healthcare applications [63]. These trends, together with more work and needed efforts in the areas of interoperability, standards, security, and legal issues [2] at both the national and international levels, will facilitate wider application of healthcare telematics, including wireless, for the whole health-care sector. This will enable offering better service to the citizen.

In conclusion, the following are some recommendations that will help enable the wider spread of wireless health systems:

1. High-level political and managerial decisions (including government and private sector), commitments, and leadership for the immediate promotion and application of wireless health systems in hospital operations and in rural-health-center services.

2. Training of physicians, paramedical, and administrative staff in the use and benefits of wireless information technology in medicine.

3. Clarification of the legal and ethical issues.

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