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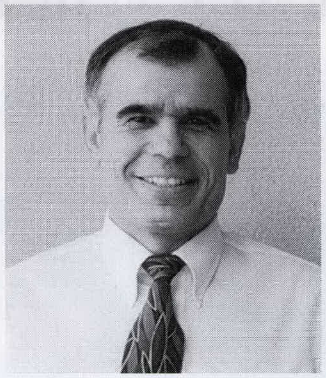

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m-Health e-Emergency Systems: Current Status and Future Directions

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Abstract

Rapid advances in wireless communications and networking technologies, linked with advances in computing and medical technologies, facilitate the development and offering of emerging mobile systems and services in the healthcare sector. The objective of this paper is to provide an overview of the current status and challenges of mobile health systems (m-health) in emergency healthcare systems and services (e-emergency). The paper covers a review of recent e-emergency systems, including the wireless technologies used, as well as the data transmitted (electronic patient record, bio-signals, medical images and video, subject video, and other). Furthermore, emerging wireless video systems for reliable communications in these applications are presented. We anticipate that m-health e-emergency systems will significantly affect the delivery of healthcare; however, their exploitation in daily practice still remains to be achieved.

Keywords: Telemedicine; health care; mobile health systems; mobile communications; emergency services; video conferencing

1. Introduction

m-Health can be defined as "emerging mobile communications and network technologies for healthcare" [1]. This concept represents the evolution of "traditional" e-health systems from desktop platforms and wired connections to the use of more-compact devices and wireless connections in e-health systems. The emerging development of m-health systems in the last decade was made possible due to the recent advances in wireless and networking technologies, linked with recent advances in nanotechnologies, compact biosensors, wearable devices and clothing, and pervasive and ubiquitous computing systems. These advances will have a powerful impact on some of the existing healthcare services, and will reshape the workflow and practices in the delivery of these services [1].

A brief review of the spectrum of m-health systems and applications, and the potential benefits of these efforts, was presented in a recent paper by our group [2]. Moreover, an edited volume was published [1], covering a number of areas in mobile m-health systems. The objective of this paper is to provide an overview of the status and challenges of m-health in emergency healthcare systems and services (e-emergency). The paper reviews recent e-emergency systems, including the wireless technologies used as well as the data transmitted (electronic patient record, bio-signals, medical images and video, and other).

Wireless telemedicine systems and services are expected to enhance traditional emergency care provision not only within the emergency department, but also in a variety of pre-hospital emergency-care situations, where geographically remote consultation and monitoring can be implemented [3, 4]. A timely and effective way of handling emergency cases can prove essential for a patient's recovery or even for a patient's survival. Especially in cases of serious injuries of the head, the spinal cord, and internal organs, the way of transporting and, generally, the way of providing care are crucial for the future of the patient. Furthermore, during cardiac-disease cases, much can be done today to stop a heart attack or to resuscitate a victim of sudden cardiac death (SCD). Time is the enemy in the acute treatment of a heart attack or sudden cardiac death. The first 60 minutes (the golden hour) are the most critical regarding the long-term patient outcome. Therefore, the ability to remotely monitor the patient and guide the paramedical staff in their management of the patient can be crucial. m-emergency becomes important in facilitating access to effective and specialist-directed care. Some benefits of pre-hospital-transmitted ECG (electrocardiogram), for example – as documented by Giovas et al. [5] – are the following: reduction of hospital delays, better triage, continuous monitoring, ECG data accessible for comparison, computer-aided analysis and decision making, and pre-hospital therapy in eligible subjects with acute myocardial infarction (AMI). This paper provides an overview of the main technological components of m-health e-emergency systems.

The structure of the paper is as follows. Section 2 covers an introduction to wireless-transmission technologies, followed by Section 3, which covers the presentation of emerging wireless video systems for reliable communications. In Section 4, an overview of m-health e-emergency systems is documented, based on published journal and conference papers, and book chapters. Section 5 addresses the future challenges, and Section 6 provide the concluding remarks.

2. Wireless Transmission Technologies

In this section, we briefly describe the main wireless technologies that are used in wireless telemedicine systems, namely GSM, 3G (W-CDMA, CDMA2000, TD-CDMA), satellite, and wireless LAN (WLAN). Emerging wireless technologies, such as WiMax, home/personal/body-area networks, ad-hoc, and sensor networks are also described. These systems are summarized in Tables 1a and 1b.

GSM is a cellular system currently in use, and it is the second generation (2G) of the mobile-communication networks. It had been designed for voice communication (circuit switched), but it can also carry data. In the standard mode of operation, it provides data-transfer speeds of up to 9.6 kbps, whereas the enhanced technique, High-Speed Circuit-Switched Data (HSCSD), makes possible data transmissions of up to a maximum of 115 kbps [6]. The evolution of mobile telecommunication systems from 2G to 2.5G (iDEN, 64 kbps; GPRS, 171 kbps; EDGE, 384 kbps) and subsequently to 3G (W-CDMA, CDMA2000, TD-CDMA) systems facilitates both an always-on model (as compared with the circuit-switched mode of GSM), as well as the provision of faster data-transfer rates, thus enabling the development of more-responsive telemedicine systems. High-Speed-Downlink Packet Access (HSDPA) [7] is the latest system enhancement of W-CDMA networks, resulting in higher data-transfer speeds, improved spectral efficiency, and greater system capacity. With a theoretical peak of 14.4 Mbps (typically, around 1 Mbps), telemedicine systems can benefit from data-transfer speeds currently only feasible on wired communication networks [6, 8].

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 beyond. Satellite links also have the advantage of coverage all over the world [9], but require line of sight and comparably higher power for similar bit rates.

WLAN is a flexible data-communications system, implemented as an extension to or as an alternative for a wired LAN. Using radio-frequency (RF) technology, WLANs transmit and receive data over the air, minimizing the need for wired connections. Thus, WLANs combine data connectivity at tens of Mbps with limited user mobility, 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. However, WLAN coverage is limited in distance to an area covering about 100 meters per cell (access point), or the coverage area of a "private" entity, as, for example, the hospital premises, with the use of multiple access points.

To extend coverage over larger distances, wireless mesh networks are also being considered. These networks are peer-to-peer multi-hop wireless networks, in which stationary nodes take on the routing functionality, thus forming the network's backbone. Basically, these act as a gateway to high-speed wired networks for mobile nodes (clients), which communicate in a peer manner.

WiMax is a wireless digital communications system defined by the IEEE 802.16 standard. Its advantage over WLANs lies in the fact that WiMax can provide broadband wireless access up to 50 km for fixed stations, and 5 km-15 km for mobile stations. It is thus intended for wireless "metropolitan-area networks" (WMANs) [10]. It is anticipated that utilization of this attractive feature will lead to a vast deployment of WiMax systems. However, the adoption of WiMax at this point in time is still in an early phase. Today, wireless LANs and MANs are becoming more widely recognized as general-purpose connectivity alternatives for a broad range of applications. These technologies have slowly started penetrating the health sector.

Home/personal/body-area networks allow connectivity of devices in the vicinity of tens of meters. Bluetooth or RF technologies may be incorporated to set up such networks. In disaster-control cases, Bluetooth connectivity may be utilized to link ad-hoc networks to existing cellular networks.

While the aforementioned wireless systems are based on infrastructure and base stations connected to a wired backbone network, ad-hoc and sensor networks do not require any wired infrastructure. Mobile ad-hoc networks, or MANETs, are a collection of geographically distributed mobile nodes that interact with one another "on the move" over a wireless medium, instead of communicating wirelessly to a base station [11]. These kinds of networks are particularly useful in the absence of a wired infrastructure, or under strict time constraints, when no time is available to set up a network. This characteristic may prove particularly useful for emergency systems. Wireless sensor networks, WSNs, are differentiated from MANETs, which are more human-oriented, and instead are focused on interaction with the environment. Wireless sensor networks incorporate sensors and actuators and, environment-oriented as they are, they measure and can influence this environment according to the occasion (as documented by Akyildiz et al. [12]), before the recorded information is communicated wirelessly for further processing. They are hence somewhat embedded in the environment [11]. Besides their numerous applications, wireless sensor networks are also applicable in the health sector, where they may be used to monitor (for example) post-surgery state and recovery, or surveillance of chronically ill patients.

3. Current and Emerging Methods for Reliable Wireless Video Communications

The transmission of medical video images over wireless-communication channels has introduced several challenges over standard video-communications methods. Clearly, for e-emergency systems, there is a strong demand for high bandwidth, and a requirement for high quality and short time delays. These requirements are further complicated by frequent communications errors associated with wireless channels. In this section, our focus is on the use of error-control mechanisms for maintaining acceptable video quality levels in wireless communications channels.

In a typical video-communication system, the original video sequence is source encoded, packetized in RTP (real-time transport

Table 1a. Mobile telephony and satellite communication networking technologies and standards.

Type	Sub-Type	Frequency Band	Data-Transfer Rates	Coverage
GSM	GSM-900	900 MHz	9.6-115 kbps. Typically about 10 kbps	Cellular network coverage, typically over 90% of a country, or region
	GSM-1800	1800 MHz	as above	as above
	GSM-1900	1900 MHz	as above	as above
GPRS	GPRS	900/1800/1900 MHz	9.6-171.2 kbps. Typically between 30-50 kbps	as above
EDGE	EDGE	as above	9.6 -384 kbps. Typically between 75-135 kbps	as above
3G/UMTS	FDD, W-CDMA	1920-1980 MHz UL, 2110-2170 MHz DL	144 kbps - 2 Mbps. Typically between 220-384 kbps	Cellular network coverage, typically over 80% of a country or region
	TDD, TD/CDMA	1900-1920 MHz UL, 2010-2025 MHz DL	as above	as above
	HSDPA	as above	up to 14.4 Mbps. Typically between 400 kbps - 2 Mbps	as above
Satellite	Satellite	1980-2010 MHz UL, 2170-2200 MHz DL		Satellite footprint covers part of the globe; typically global with a number of satellites
	ICO	C, S band	2.4 kbps	as above
	Globalstar	L, S , C band	up to56 kbps	as above
	Iridium	L, Ka band	2.4 - 10 kbps	as above
	Inmarsat	L, C band	4 - 492 kbps	as above
	Thuraya	L, C band	9.6 - 144 kbps	as above
	IntelSat	C, Ku band	64 kbps - 45 Mbps	as above
	MSAT	L band	1.2 - 4.8 kbps	as above

Table 1b. Wireless LAN, WiMax, BAN, PAN, and Home Net communication networking technologies and standards.

Type	Sub-Type	Frequency Band	Data-Transfer Rates	Coverage
Wireless LAN	IEEE 802.11	2.4 GHz	2 Mbps	About 100 m for single access point, typically enterprise area with multiple access points
	IEEE 802.11a	5 GHz	20 Mbps	as above
	IEEE 802.11b	2.4 GHz	11 Mbps	as above
	IEEE 802.11g	2.4 GHz	22 - 54 Mbps	as above
	Hiperlan1	5 GHz	20 Mbps	as above
	Hiperlan2	5 GHz	54 Mbps	as above
	HiSWANa	5 GHz	54 Mbps	as above
WiMAX	TDD	3.5 GHz	45 Mbps/ channel	Typically 50 km for fixed stations and 5 km-15 km for mobile stations
	FDD	3.5 GHz	45 Mbps/channel	as above
	TDD	5.8 GHz	45 Mbps/channel	as above
BAN, PAN	Bluetooth	2.4GHz	1 Mbps	10 m coverage, extended to 100 m in later standards
Home Net.	HomeRF 1.0	2.4 GHz	2 Mbps	home coverage, 10s of meters
	HomeRF 2.0	2.4 GHz	10 Mbps	as above
Sensor Networks	Mostly based on IEEE 802.15.4 standard for WPANs, as e.g. ZigBee	Industrial, scientific and medical (ISM) radio bands; 868 MHz in Europe, 915 MHz in the USA and 2.4 GHz	Typically low bit rates with low power requirements	Coverage is application dependant, dictated by number of sensors and density of deployment

protocol) [13] format, channel encoded, and transmitted over the packet-based network. The reverse procedure is followed at the decoder's side. An important new aspect of the incorporated scheme relies in the presence of a back channel, providing a low-bandwidth communications link from the decoder back to the encoder. Video-communication errors can be classified as randomly distributed single-bit errors, packet losses, burst errors, and packet-delay variations. To compensate for delay variations, a buffer is maintained at the decoder, which positions the real-time transport protocol packets according to their sequence number into their initial order. However, packets with significant delays are dropped, and retransmission is often unattainable, due to significant time delays. Since video-compression standards rely on predictive-coding methods (motion estimation and compensation), packet loss may be propagated to different parts of the video. Error-control mechanisms are generally classified in terms of encoder error-resilient methods, decoder error concealment, and joint encoder-decoder error control.

We next provide an overview of basic, encoder error-resilient methods. More-advanced and recent error-resilient methods are described in Section 3.1. We begin this discussion with basic definitions, to help understand the characteristics of error-resilient control mechanisms. For each concept, we briefly provide its relation to error control.

Digital video can be thought of as a sequence of video frames. The first frame is intra-code, also termed an I-frame. I-frames are encoded utilizing only information of the current frame, thus requiring more bits to encode. Subsequent frames maybe inter-coded, referencing previously decoded frames (P-frames), or both previous and subsequent frames (B-frames, for bidirectional). To limit error propagation between frames, a video-compression algorithm may introduce periodic or random I-frames.

A frame can be divided into independently transmitted and decoded slices. This approach enables better compression and, in wireless environments, where out-of-sequence packet delivery is possible, reduces decoding delay. A slice can be broken down into macroblocks (MBs), and MBs into blocks. An MB is a collection of spatially adjacent pixels, usually forming a rectangular area, which can be independently processed. At the frame level, error propagation may be limited to the extent of a slice.

Video bit-stream information is encoded using variable-length coding (VLC). In VLC, scalars or vectors are encoded according to their frequencies of occurrence. Frequent scalars or vectors are assigned short codes, while infrequent scalars or vectors are assigned longer codes. This results in significant compression of the bit stream. Unfortunately, a single bit error also makes a standard VLC bit-stream un-decodable. The problem is a direct consequence of the use of variable-length codes. In standard VLC, following a single bit error, there is no way to determine when the current (decoded) code ends and the new one begins. To limit the extent of these errors, we employ re-synchronization markers and reverse variable-length bit coding (RVLC). Using re-synchronization markers [14], following an error, the decoder simply jumps to the next marker and resumes decoding onwards. In RVLC [15], the decoder jumps to the next marker and starts decoding backwards, thus utilizing uncorrupted bits.

Following our brief introduction to basic error-resilient methods, we provide a brief overview of decoder-based error concealment. In error concealment, the decoder uses spatial or temporal interpolation methods to reconstruct missing data. The basic methods can be classified as ([14, 16-25] and references therein):

- Spatial interpolation from surrounding pixels of the same frame (MPEG-1/H.261),
- Temporal interpolation from neighboring video frames (without motion estimation in MPEG-1/H.261), and
- Motion-compensated temporal interpolation from neighboring video frames (MPEG-4/H.263).

For medical-video applications, we may need to limit interpolation to avoid any adverse effects on the diagnosis.

In joint encoder-decoder error control, the encoder and the decoder work together to minimize the error. These methods were introduced in MPEG-4 and H.263. In this case, we require a back channel from the decoder to the encoder. The back channel can be used to adapt encoding to available bandwidth, and most importantly, to inform the encoder of lost packets during the transmission. Once the encoder becomes aware of which packets were lost, subsequent encoding can be adapted to avoid any reference to them, in effect synchronizing the encoding process with real-time decoding. A comprehensive review of feedback-based error control can be found in [26]. The basic methods involve the use of feedback information for error tracking, and to also guide the selection of a reference frame [14, 26]. The use of joint encoder-decoder error control holds great promise in emergency applications. Here, we note that the back channel also facilitates the development of collaborative environments, where a medical expert at the decoder side can help guide the medical exam.

3.1 Error-Resilient Methods in Video-Compression Standards

We briefly discuss the use of error-resilient methods in a variety of video-compression standards (see Table 2). In describing error-resilient methods, we follow a hierarchical approach, presenting general bit-stream methods first, followed by frame-based methods, slice methods, and macroblock-based methods.

Table 2. Error-resilience techniques.

Technique		Video Coding Standards	Channel Adaptive Technique
Robust Entropy Coding	Resync Markers	MPEG-1/ H.261	NO
	RVLC	MPEG-4/ H.263	NO
Data Partitioning		MPEG-2/ H.263	NO
FMO		H.264/AVC	NO*
ASO		H.264/AVC	NO*
Redundant Slices		H.263	NO*
SP/SI		H.264/AVC	YES*
Intra Updating	Periodic I-MB	MPEG-4/ H.263	NO*
	Preemptive I-coding	MPEG-4/ H.263	NO*
	Random I-coding	MPEG-4/ H.263	NO*
	Intra block refreshing by RD	H.264/AVC	NO*
Multiple Reference		H.263	NO*
UEP & LC		MPEG-4/ H.263	YES*
MDC		MPEG-4/ H.263	YES*

*Error-resilience techniques can be used both in a non-channel-adaptive and in a channel-adaptive environment. The table records the earliest video-coding standard to adopt the listed error-resilience techniques. No classification is made between versions of these standards. Thus, these techniques or enhanced versions of them are included in forward standards. Some of these techniques may also be compatible with prior standards.

To accommodate the wide variety of bandwidths, the new compression standards rely on scalable coding methods. In scalable coding, a video is usually encoded into a base layer and many enhancement layers. The base layer provides satisfactory-quality video that must be decoded by all communications channels, regardless of how little bandwidth is available. Then, according to bandwidth availability, a number of enhancement layers are added to the base layer, to produce higher-quality video. Here, the base layer is protected more strongly from the enhancement layers. To this end, enhanced forward error correction (FEC) [27] and automatic repeat request (ARQ) schemes are employed [14, 16, 17]. The term unequal error protection with layered coding (UEP & LC) is used to describe this scheme (see Table 2).

Alternatively, or additionally, in multiple-description coding (MDC), a data source is encoded into a number of descriptions that are correlated and of roughly equal importance. Here, the source sequence is coded into multiple bit streams with minor differences, which are in turn transmitted independently. Then, the decoding of a single bit stream provides adequate-quality video, while the decoding of multiple robust streams provides for higher quality [14, 28]. In yet another method that uses multiple bit streams, in H.264/AVC, the decoder may be allowed to switch between two or more pre-encoded bit streams (of different bandwidths and qualities) from the same source. In H.264/AVC, this is facilitated through the use of synchronization/switching pictures SP/SI [29], [30]. The decoder triggers a bit stream switch through a back-channel, regaining synchronization.

In intra-updating, we limit prediction within the current frame, without any reference to previous frames. At the highest-level, we use I-frames to reinitialize the prediction. Similarly, we can use intra-coded macroblocks (MBs) with periodic intra-coding of all MBs, preemptive intra-coding based on previous knowledge of the channel-loss model, and random placement [14, 16, 17]. In intelligent intra-block refreshing by rate distortion (RD), we select a block-coding scheme that minimizes a certain cost function (adopted by the H.264/AVC [31, 32]).

In contrast, in multiple- (two or more) reference picture-motion compensation, we can extend motion compensation to more than two references. The use of multiple reference frames provides the decoder with a larger selection of reference frames for use in error concealment via temporal interpolation [18-22].

In arbitrary slice ordering (ASO) [19, 20, 22], slices can be transmitted independently of their order within a picture. As a result, they can be also decoded out of sequence, reducing the decoding delay at the decoder. ASO is particularly effective in environments where out-of-order delivery of a packet is possible, such as the Internet or wireless networks, or packet-based networks in general. To recover from the loss of an entire slice, H.264/AVC allows the transmission of redundant slices (RS). Redundant slices may be coded differently than the primary slices. In data partitioning, a primary slice can be divided in up to three parts, and then transmitted with unequal error protection (UEP). This approach allows us to use higher error protection in critical parts of the video.

In flexible macroblock ordering (FMO), macroblocks within a slice are transmitted in different orderings [33, 34]. The use of different transmission orderings provides for better error recovery. The approach improves over raster-scan ordering, which faces large problems with burst errors, and also allows region-of-interest (ROI) coding and recovery. Furthermore, arbitrary spatial placement of blocks provides for better error concealment via spatial interpolation.

4. m-Health e-Emergency Systems

In his seminal paper "Le Telecardiogramme," Einthoven demonstrated 100 years ago the successful transmission of about one hundred ECGs through a distance of 1.5 km, connecting his lab with the University Hospital in Holland [35]. Furthermore, according to Giovas et al. [5], 60 years later in Belfast, in 1966, pre-hospital cardiac care was "moved" from the coronary care into the community by treating the early complications of acute myocardial infarction. In the following year, pre-hospital one-lead telemetry was presented in Miami [5], whereas in 1970, Uhley [36] published his experience with one-lead wireless-telemetry ECG. The wireless transmission of 12-lead ECG over a cellular network was demonstrated in 1987 by Grim et al. [37]. In the following years, numerous ECG monitoring systems were developed that were also transmitting additional vital bio-signals and, in some cases, medical images and videos. The most recent of these systems are summarized in the following section.

4.1 An Overview

The MEDLINE and IEEE Xplore databases were searched with the following keywords: wireless telemedicine emergency, wireless telemedicine ambulance, wireless telemedicine disaster, wireless ambulance, wireless disaster, and wireless emergency. The number of journal papers found to be published under these categories was around 180. Out of these, a total of 33 applications were selected, and are briefly summarized in Table 3. These systems covered the whole spectrum of wireless emergency telemedicine applications presented during the recent years. The papers were grouped using the wireless-technologies types, which were GSM/GPRS, 3G, and satellite and wireless LAN. The data transmitted were coded under the columns "ECG and other bio-signals;" "IMG," for medical images or patient images; "EPR/Data," for electronic patient records or just data; and "Video," for video conferencing or medical video transmission. The column "Web" identifies which of the applications were developed supporting Web technologies. The majority of the applications (21) used the GSM/GPRS network, while a lot of applications used wireless LAN (11), in order to transmit data. The applications presented in the other two categories, "3G" and "Satellite," were rather limited.

In the first group of applications, which use the mobile-telephony networks GSM/GPRS, we had the highest number of applications. These applications could be divided into two main categories: those transmitting bio-signals such as ECG, oxygen saturation, blood pressure, etc.; and those transmitting medical images, or just pictures of a patient. Some of the applications presented were a combination of both categories. Most of the applications concerned the transmission of bio-signals and images in order to support pre-hospital treatment, such as [42, 44], or the transmission of bio-signals in order to monitor patients with chronic heart diseases [50]. Some of the applications concerned the transmission of images only [54-57]. Imaging modalities are rapidly changing, thus affecting the medical procedures and the need for new telemedicine applications in order to support these procedures. Finally, one application was used for the access of electronic patient records [59].

The second group covered those applications that use 3G mobile networks. The first application [60] concerned the transmission of bio-signals and images of the patient, something that has been extensively presented by many applications in earlier stages. The second application [61] investigated the transmission

Table 3a. Selected applications of m-health e-emergency systems that use GSP/GPRS and 3G networks.

Commun. Technol.	Author	Year	Data Transmitted: ECG and/or other signals	Data Transmitted: IMG	Data Transmitted: EPR/ DATA	Data Transmitted: Video	Web application	Comments
GSM/GPRS	Karlsten *et al.* [38]	00	√					Ambulance triage support
	Yan Xiao *et al.* [39]	00	√			√		Ambulance neurological examination support
	Anantharaman *et al.* [40]	01	√					Pre-hospital support
	Rodrvguez *et al.* [41]	01	√					Cardiac arrest treatment
	Istepanian *et al.* [42][43]	01	√	√				Transmission of ECG data and still images for emergency use. Compression of ECG using a wavelet compression method
	Pavlopoulos *et al.* [44]	01	√	√				Portable teleconsultation medical device
	Chiarugi *et al.* [45] & Kouroubali [46]	03 05	√					Transmission of 12-lead ECG in order to support ambulance and rural health centers emergencies (HygeiaNet)
	Kyriacou *et al.* [47]	03	√	√				Wireless transmission of biosignals and images from a Rural Health Center and a moving ambulance vehicle to a central hospital
	Clarke *et al.* [48]	04	√					Wireless connection to sensors and transmission of data from an ambulance
	Kyriacou *et al.* [49]	05	√	√				Ambulance emergency support through wireless transmission of biosignals and images
	Salvador *et al.* [50]	05	√				√	Transmission of ECG and other parameters to support patients with chronic heart diseases
	Clemmensen *et al.* [51]	05	√					Transmission of ECG signals to a cardiologist's PDA to improve time to reperfusion
	Campbell *et al.* [52]	05	√					Wireless transmission of ECG from Emergency medical care personnel to the department and through wireless LAN to the on-call cardiologist who is carrying a PDA
	Giovas et. al [5],	06	√					Wireless transmission of 12-lead ECG from a moving ambulance vehicle to a central hospital
	Sillesen *et al.* [53]	06	√					Transmission of ECG signals to a cardiologist's PDA in order to improve time for PCI treatment
	Schôchinger *et al.* [54]	99		√				Early hospital admission
	Reponen *et al.* [55]	00		√				Transmission of CT scans using GSM and PDAs. Images transmitted to a neuroradiologist for preliminary consultation
	Oguchi *et al.* [56]	01		√			√	Use of personal handyphone system to transmit CT images using a web based application
	Voskarides *et al.* [57]	02		√				Transmission of X-ray images in emergency orthopedics cases
	Hall *et al.* [58]	03			√			Wireless access to Electronic Patient Record
	Kontaxakis *et al.* [59]	06				√		Tele-echography system and 3D-ultrasound
3G	Chu *et al.* [60]	04	√	√		√		Trauma care through transmission of patient's video, medical images and ECG
	Garawi *et al.* [61]	06				√		Tele-operated robotic system for mobile Tele-Echography (OTELO-Project)

Table 3b. Selected applications of m-health e-emergency systems that use satellite and wireless LAN networks.

Commun. Technol.	Author	Year	Data Transmitted: ECG and/or other signals	Data Transmitted: IMG	Data Transmitted: EPR/DATA	Data Transmitted: Video	Web application	Comments
Satellite	Kyriacou *et al.* [47]	03	√	√				Wireless transmission of biosignals and images from a Rural Health Center and a moving ambulance vehicle to a central hospital
Satellite	Strode *et al.* [62]	03		√				Examination of trauma using focused abdominal sonography (military)
Satellite	Vieyres *et al.* [63], & Canero *et al.* [64]	05				√		Tele-operated robotic system for mobile Tele-Echography (OTELO-Project)
Satellite	Virgin Atlantic Airways [65]	06	√	√				The Tempus 2000 device will be used for monitoring a passenger's blood pressure, pulse rate, temperature, ECG, blood oxygen and carbon dioxide levels in emergency cases.
Wireless LAN	Garrett *et al.* [66]	03				√		Echocardiogram transmission in cardiac emergency from an ambulance in transit to a tertiary care facility
Wireless LAN	Lorincz *et al.* [67]	04	√					Sensor networks for emergency response, system tested using two vital signs monitors
Wireless LAN	Clarke *et al.* [48]	04	√					Wireless connection to sensors and transmission of data from an ambulance Telecare project
Wireless LAN	Maki *et al.* [68]	04	√					Wireless monitoring of sensors on persons that need continuous monitoring, when an emergency occurs the specialized personnel listens a sound alarm or a notification through mobile phone
Wireless LAN	Campbell *et al.* [52]	05	√					Wireless transmission of ECG from Emergency medical care personnel to the department and through wireless LAN to the on-call cardiologist who is carrying a PDA
Wireless LAN	Palmer *et al.* [69]	05	√				√	Wireless blood pulse oximeter system for mass casualty events designed to operate in WIFI hotspots. The system is capable of tracking hundreds of patients. Suitable for disaster. Control
Wireless LAN	Lenert *et al.* [70]	05	√		√			Medical care during mass casualty events, transmission of signals, alerts monitor.
Wireless LAN	Nakamura *et al.* [71]	03				√		Wireless emergency telemedicine LAN with over 30 Km distance used in the Japan Alps used for mountain climbers emergency telemedicine
Wireless LAN	Pagani *et al.* [72]	03		√			√	Web based transmission of cranial CT images. Comparison of the results
Wireless LAN	Kim *et al.* [73]	05		√				Transmission of CT and MRI images through a PDA and wireless high-bandwidth net to neurosurgeons
Wireless LAN	Hall *et al.* [58]	03			√			Wireless access to Electronic Patient Record

of real-time ultrasound video, captured via a remotely controllable robotic arm. This application was developed by P. Vieyres and coworkers [63], and initially exploited using satellite links (see Section 4.2 for more details).

Moving to the next category of communication links, the satellite links, we only found four new significant studies. We do note, however, that a significant number of studies using satellite links were published prior to these studies (not reported here). The applications found here mostly concerned the transmission of ultrasound video [62-64]. Two of the papers [63, 64] also included the use of a robotic mechanism in order to remotely control the ultrasound acquisition, as described above in the section on 3G networks, while the other two papers [47, 65] concerned the transmission of bio-signals and images for emergency cases. The Virgin Atlantic press release [65] announced the first wireless telemedicine system that will be adopted by a major airline carrier, which will be available on all its flights.

The last category of applications covered the use of wireless LANs. Basically, these applications were for disaster-control cases, where a lot of injured people might be concentrated in a small area, and a wireless LAN was used in order to monitor the condition of these people. Most of the applications presented here concerned the transmission of bio-signals and the use of sensor networks [67-70]. Three of the applications were transmitting images [71-73], with CT (computed tomography) images transmitted in [72] and CT and MRI (magnetic resonance imaging) images transmitted in [73]. Also, in an update to [72, 73], one application was used for the access of electronic patient records [58].

4.2 Case Study 1: Mobile Emergency Health Services in HYGEIAnet [45, 46]

The HYGEIAnet represents the effort of more than 15 years of work of the e-health laboratory at the Institute of Computer Science, Foundation for Research and Technology-Hellas (FORTH), led by the late Prof. Stelios Orphanoudakis. The HYGEIAnet covers the design, development, and deployment of advanced e-health and m-health services at various levels of the healthcare system, including primary care, pre-hospital health emergency management, and hospital care on the island of Crete, Greece, as illustrated in Figure 1 [45, 46, 73, 74].

The HYGEIAnet covers the island of Crete. Crete has a local population of approximately 600,000, seven hospitals, 16 primary health-care centers, and a large number of isolated communities in remote locations. The population more than doubles during the summer period, and accidents more than triple during the summer period, with more than 42% of accidents involving tourists. The ambulance service in Crete is supported with the IASO information system, covering triage protocols, coordination, and management of resources [46], covering the island, as illustrated in Figure 1. The IASO system has been in daily operation since 1997. It consists of the following five modules [46, 74]:

1. Operator/Dispatcher Module: This allows creating, completing, and printing the electronic "incident card." Based on specific algorithms (online triage protocols), it offers help with regard to incident-severity estimation and the selection of the most-appropriate resources (e.g., ambulance car or mobile unit).

2. Doctor Application/Telematics Module: Mobile units support the transmission of vital signs and ECGs [45] directly to the doctor's application at the dispatching center, allowing for remote monitoring and management of the patient within the ambulance.

3. Administrative Module: This supports the analysis of the contents of the emergency-incident archive, enabling efficient and effective administrative decision making.

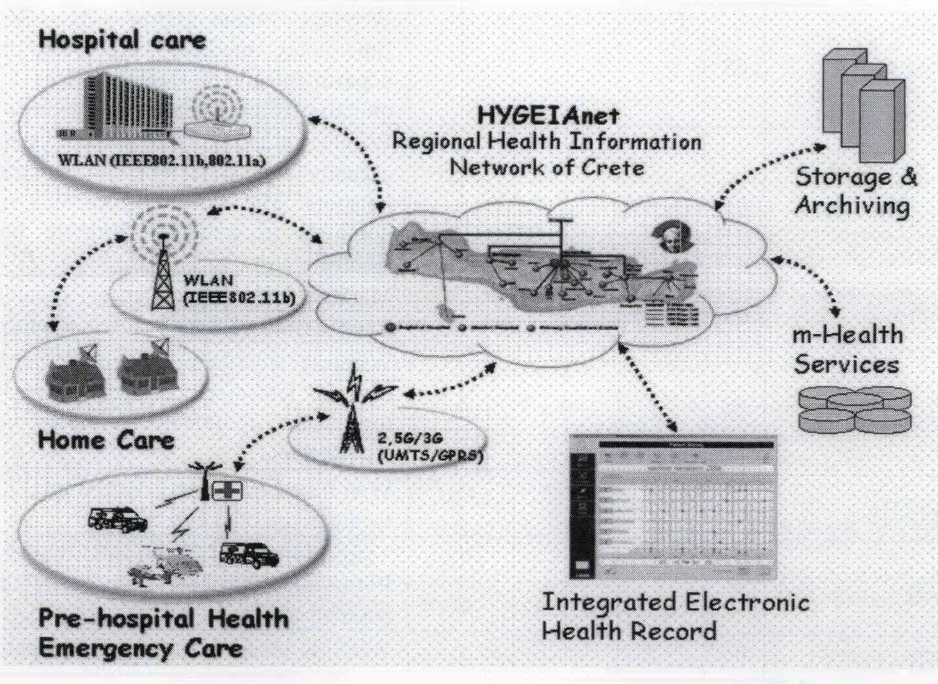

Figure 1. m-services and technologies in HYGEIAnet, as shown on the project's Web page, http://www.hygeianet.gr/ [74] (©2002 HYGEIAnet, used with permission).

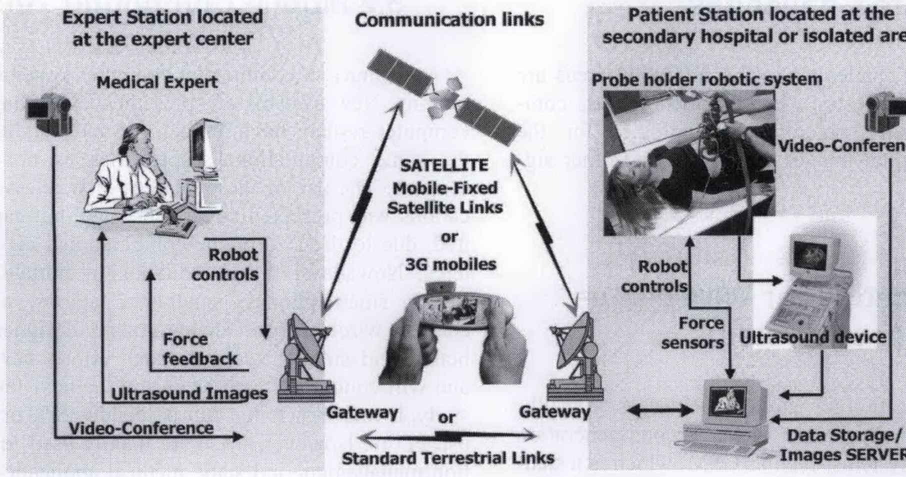

Figure 2. The OTELO system, illustrating the expert station, the patient station, and the communication links, as shown on the project's Web page, http://www.bourges.univ-orleans.fr/ otelo/home.htm [63] (©2001 OTELO IST-2001-32516, used with permission).

4. GPS/GIS Module: The dispatching center supports a GPS satellite geographic information system, which depicts the exact position of the ambulance.

5. Triage Protocols Module: This module targets the differentiation of urgent from non-urgent calls, to enable the implementation of a triage mechanism to effectively manage ambulance resources. Protocol categories cover allergies, heart and respiratory failure, stroke, multi-trauma, abdominal and thoracic pain, labor, hemorrhage handling, and others. Patient triage is a dynamic process, involving repeated reassessment of the patient until the patient has received definitive treatment [46].

The deployment and use of the HYGEIAnet services has demonstrated significant economic, clinical, and access-to-care benefits. Furthermore, 65% of pre-hospital health-emergency episodes have been managed by paramedics. With regard to e-health services in cardiology, the evaluation study also revealed significant benefits. Detailed preliminary evaluation results were reported in [74]. The service had a rather strong diagnostic impact: only in nine out of 21 cases was the patient immediately transferred to the hospital. Since the health-care centers are in remote locations and all the patients seen would normally have been referred and transported to the regional hospital for evaluation, this represented a clear saving of time, cost, and resources. The HYGEIAnet was a finalist in the 2005 eEurope awards.

4.3 Case Study 2: A Tele-Operated Robotic System for Mobile Tele-Echography: The OTELO Project [63]

The objective of the European OTELO project was the development of an advanced tele-echography robotic system to enable a medical ultrasound expert, located at an expert site (e.g. the closest university hospital), to perform echography on a distant patient, located at an isolated site, and to make a reliable echographic diagnosis. The OTELO system consists of the following three subsystems [63], as illustrated in Figure 2:

1. The expert station, where the ultrasound expert receives – on a control monitor and in almost real time – the ultrasound images of the patient's organ. Based on these images, he or she can modify the orientation of the remote real ultrasound probe by changing the position of the virtual probe. The changes can be a slight rotation along the virtual probe axis, an inclination from the vertical axis, a rotation around the vertical axis, or an *x-y* displacement within the chosen workspace. A graphical user interface [64] allows the specialist to record, zoom, and freeze the received ultrasound image to make a first diagnosis. The expert can communicate with the remote patient via videoconferencing.

2. The patient station is equipped with the robotic probe-holder system, an ultrasound device and, a videoconference link. The six-degree-of-freedom mechanical structure can hold several types of currently manufactured ultrasound probes, to be found in various secondary hospitals or dispensaries. It receives the positioning data from the expert virtual probe localization sensor, and sends back to the expert station the force exerted by the real probe on the patient's skin. During the tele-operated diagnosis, the robot is maintained over the patient by a paramedic.

3. The communication link between the two stations can be either terrestrial, via ISDN lines, or via satellite, or, more recently, via 3G wireless communications.

Echographic examinations were performed successfully using ISDN [76], satellite, and 3G communication links [61]. Moreover, using satellite and three ISDN connections the system was exploited between the Nicosia General Hospital and the Kyperounta Medical Centre in Cyprus, with the University of Tours and the Barcelona Hospital Clinic (see http://www.bourges.univ-orleans.fr/otelo/home.htm). These first results showed the feasibility of that device, and the possibility of obtaining good views from the remote site. It allows the expert to make a comparable diagnosis to that made with a standard echography system. Future work will exploit the use of the OTELO system in emergency cases, including the ambulance vehicle via 3G connectivity.

5. Future Challenges

In this section, future challenges in the following areas are given: communication for wireless e-emergency systems, computer technology, bio-signals, emerging technologies for the transmission of wireless digital images and video, and other significant issues.

5.1 Communication for Wireless e-Emergency Systems

Until today, communication for wireless e-emergency healthcare systems was performed mainly using second-generation mobile telecommunication systems, such as GSM, which is a standard used almost everywhere in the world. During the last few years, the introduction of new mobile telecommunication systems (2.5 generation) – such as the GPRS system, which provides much higher bandwidth (theoretically, up to 171.2 kbps; typically about 35 kbps [2] – has enabled the transmission of much more information, which can prove useful for healthcare providers and crucial for a patient's treatment.

Recently, in many countries 3G mobile networks, such as the UMTS ([8], UMTS forum) are currently installed and operating. These provide bandwidth up to 2 Mbps (maximum; typically hundreds of kbps), which will enable the transmission of more information, such as continuously transmitting 12 leads of ECG when monitoring cardiac patients from a moving ambulance. Furthermore, the current introduction of new services, such as video telephony through wireless networks, will be an addition that can help with communications between a health-care provider (nurse, paramedics) and an expert doctor. Another important factor is the installation of wireless networks in cities (e.g. WiMAX, with tens of Mbps), which will be able to significantly improve communication in wireless health-care systems operating within city boundaries. WiMAX is currently being standardized, with some commercial applications already installed. The use of such networks will be very important, because health-care providers will have immediate and high-speed telemedicine access from anywhere in the area of a city.

Using sensor networks, data gathering and computation can be deeply embedded into the physical environment. This has the potential of impacting provision of e-ambulatory care, e.g., resuscitative care (see Lorinz et al. [77]), by allowing vital signs to be automatically collected and fully integrated into the patient-care record and used for real-time triage, correlation with hospital records, and long-term observation.

Beyond these networks, the current activities in what are termed as the 4G (fourth-generation) mobile networks promise ubiquitous access to differing radio network technologies. Beyond extended coverage, they will thus also offer the most-effective connection mode at the point of contact, even simultaneously using more than one wireless access technology, and seamlessly moving between them.

The use of locating systems, such as GPS (Global Positioning System), GIS (geographical-information systems), and intelligent traffic-control systems, also have the potential to improve healthcare services. Examples include situations when a moving ambulance is trying to reach a patient using the fastest route, or when an ambulance carrying a patient is trying to get to the base hospital.

5.2 Mobile Computing Technology

Changes in commercial computer systems are rapid and continuous. New systems are presented every day. Modern portable computer systems have smaller size and weight, but provide almost the same computational capabilities as non-portable computer systems. The use of these devices in wireless telemedicine applications was presented some years ago, but capabilities were limited, due to the size or the computational capabilities of the systems. Nowadays, the introduction of portable devices, such as PDAs, smart phones, small-size laptops, and pen-tablet PCs enables wireless-telemedicine-system designers to create faster, better, and smaller systems. Such efforts have already appeared and will continue to appear during the next few years. In a recent study, it was shown that approximately 25% or more of physicians use PDAs. However, these are mainly used for personal-information management and static medical applications, without exploiting the features of wireless Internet connectivity [78].

5.3 Bio-Signals

Bio-signal acquisition is another technological field that affects wireless telemedicine systems. Until now, the collection of bio-signals [79-82], such as ECG, was performed using expensive devices, which could only be handled and supported by medical personnel. Nowadays, the collection of bio-signals such as ECG can be performed by very small devices. These are not always devices on their own, but they might connect to a PC in order to display the signals, to a mobile phone in order to send the signals, or even have Bluetooth or GPRS connectivity to wirelessly transfer the signals. They might be wearable, have the shape and weight of a necklace, etc. These devices will enable the use of wireless telemedicine systems almost anywhere, and at less cost. Such devices can be used for home-care purposes much more easily than standard medical devices.

5.4 Emerging Technologies for the Transmission of Wireless Digital Images and Video

The future needs for signal and image-processing applications in e-health will involve a multitude of different signals, ranging from one-dimensional signals, such as the ECG, to real-time color video signals. There will also continue to be strong demand to move more and more services to smaller, lower-power, more-compact computing devices. The challenge to e-health signal- and image-processing systems is to deliver the highest possible quality while minimizing the computational power and bandwidth requirements. We discuss future challenges from the perspective of the development of real-time, collaborative systems.

There has been substantial progress made in the processing and analysis of one-dimensional biomedical signals [83]. Their bandwidth requirements can usually be met, and their strong diagnostic value makes them an essential part of most future collaborative systems. They are essential for continuous, real-time monitoring. Clearly, if a medical condition can be detected using a one-dimensional signal such as the ECG, then we should avoid using images and/or video to accomplish the same task. In joint-processing, it is important to consider the use of one-dimensional signals to reduce the bandwidth and computational requirements of higher-dimensional signals. Furthermore, we should consider scalable coding systems, where one-dimensional biomedical signals belong to the base layer, with strong protection from transmission errors.

Due to the high-bandwidth requirements, image- and video-compression methods will continue to play an important role in future, real-time collaborative environments [49, 63]. At the most basic level, medical image-quality assessment is an important area of future research (see http://live.ece.utexas.edu/research/Quality/index.htm). Traditional mean-square-error measurements do not necessarily correspond to perceptual quality, and may correspond even less to diagnostic quality. As an example, image-quality assessment over the near-regions of ultrasound video is not useful, while, in general, users expect the highest quality in regions that are in the focus of the ultrasonic beam. In addition, there will continue to be strong interest in region-of-interest (ROI) and object-based coding methods. The challenges associated with applying these methods require the development of effective segmentation methods.

Scalable image and video coding will see continual development [84]. For medical-imaging applications, there are many challenges in defining diagnostically relevant scalable methods. There are obvious applications in object-based scalability, not only where the object is of diagnostic interest, but also in defining the base layer and enhancement layers so that the base layer is of diagnostic significance. In transmitting video images of the patient, ongoing and future research on facial-image coding will be important in determining the patient's feelings and reactions during medical exams. There is also a need to consider new image-compression models that correspond more closely to the structured texture and image-acquisition characteristics of medical video.

From the wireless-communications perspective, video-image-compression research will continue in areas such as error resilience and error concealment [85, 86]. Especially for error-resilience methods, there will be strong interest in new encoding schemes that allow for robust decoding. For medical-imaging applications, a small percentage of errors could be tolerated and their effects minimized through error concealment. Future research in error-concealment methods should take into account the complex nature of biomedical images. Different interpolation schemes should be employed for text objects, background, and texture objects over a single video. We should also consider the development of new interpolation methods that are a function of well-established imaging parameters, such as the use of different interpolation methods for near-field and in-focus regions in ultrasound video. For in-focus regions, we can consider accurate, yet computationally expensive, methods. On the other hand, we can use fast and somewhat less accurate methods for near-field regions.

Many signal- and image-processing challenges lie in the joint processing and transmission of biomedical signals and images [49]. We list challenges in three areas: (i) multi-modality signal synchronization; (ii) joint signal, image and video compression; and (iii) interactive collaborative environments. The basic application is the development of high-quality collaborative environments, where a variety of biomedical signals and images are exchanged. There are significant synchronization issues for joint decoding. Clearly, one-dimensional biomedical signals should correspond to the video images. As an example, we note the synchronization of the ECG, respiratory, two-dimensional, and Doppler signals in ultrasound systems. In addition, we note that two-way voice communications must be synchronized to all clinical signals, as well as to real-time video images of the patient and the doctor. Resynchronization in the presence of wireless-communication errors will require innovative error-resilience methods. For well-synchronized signals and images, we can develop methods for joint-signal, image, and video compression. We offer an example in video-image compression. In cardiac imaging using ultrasound, the ECG signal can be used to predict changes in the video-imaging signal. Thus, we can appropriately adapt the rate requirements so as to allocate more rate to capture significant motion, while allocating less rate for what is anticipated to be less motion. Scalable coding for jointly coded signals, images, and video also presents significant challenges. It is important to decide how to jointly break the one-dimensional biomedical signals with the voice, images, and video to form independently encoded blocks. The base and enhancement layers in such layers should then be decided based on diagnostic measures, as well as with regards to available bandwidth. Clearly, we will require spatiotemporal scalability, as well as object-based (or region-based) quality scalability. In addition, in the future we want to consider content-based access for the jointly encoded signals.

There are many challenges associated with the use of interactive, collaborative environments. As an example, all the MPEG-2/MPEG-4 functionalities [87, 88] need to be re-thought in the context of synchronized, jointly-compressed signals. The users may be reviewing a particular signal, asking to see the corresponding signals (images or video) from other modalities. Such an interactive preview capability requires the development of fast joint-decoding methods. For real-time collaborative work, the heterogeneity of the networks, computing systems, and image displays will be best served by innovative, scalable, network-aware systems. In conclusion, we note that the high-quality robust requirements of e-health systems will only be met by addressing particular clinical needs.

5.5 Other Significant Issues

Legal, liability, and ethical issues, as well as the workflow of m-health services [89], will have to change to enable the effective and efficient use of these systems. Starting from legal issues, the introduction of new services will have to be covered by several laws: national or EU laws in the case of European countries, or federal laws for the United States. These laws will have to cover all issues, including the responsibilities during an emergency or home-care incident. Furthermore, the liability of systems will have to be covered by standards that will describe everything that a system should follow. Even though there has been significant effort in creating a standard for collecting and exchanging bio-signals [90, 91] (such as DICOM for images), no standard is widely used by manufacturers of commercial bio-signal monitors. Such issues will need to be resolved in the near future in order to cover the liability and interoperability of medical devices.

On the other hand, several ethical issues will also have to be covered when using these systems: such issues concern the exchange of medical information through public networks, thus having potential problems with security. This is currently being addressed with effective available security systems; however, the tradeoff between a "heavy" security system (thus impacting on system load and friendliness), versus a lean implementation with just-adequate security, is still a matter of intense research [92].

6. Concluding Remarks

This paper reviewed wireless technologies and emerging wireless video systems for reliable communications. It also provided an overview of recently published wireless emergency healthcare systems, in which some of the reviewed technology was presented. These systems clearly demonstrate the benefits and the need for their wider deployment.

Even though Einthoven demonstrated in 1906 the successful transmission of ECG [35], and Grim in 1987 transmitted error-free 12-lead ECG over a wireless network [37], the wide use of e-emergency systems, including the monitoring of ECG for pre-hospital care, is still lacking. Similarly, the transmission of echography video in teleradiology for various organs using satellite connections has been proven feasible and successful in numerous cases [59, 63]. Early security concerns are currently been addressed, and successful secure e-health applications are rapidly becoming commercialized, with many well-known health and IT vendors appearing in the marketplace. However, in a recent study carried out by the World Health Organization (WHO) on e-health tools and services including m-health, it was concluded that countries need the following: support in the adoption of policy and strategy for the development for e-health; advice on needs assessment and evaluation of e-health services; information on best practices and trends; and advice on e-health norms and standards. In other words, countries require consultancy services to assist in all aspects of e-health, and a need for education and training in this area [93].

The know-how and technology developed lately in disaster management is leading to the development of new approaches for emergency evaluation, triage, and treatment in pre-hospital and hospital care and services [94]. The ability to provide timely "hands-on" expertise to the trauma patient, irrespective of the specialist's location, facilitates the potential for real advancement in the field.

However, m-health e-emergency is still largely undeveloped. The success, experience, and benefits of clinical services in emergency telemedicine have only recently been published on a large scale of emergency cases by the telemedicine program at the State University of New York, at the Buffalo School of Medicine, and the Erie County Medical Center (UB/ECMC) [95]. In addition, it was shown that the use of emergency telemedicine services could result in an approximately 15% decrease in ambulance transports when it was added to the pre-hospital care-provider's services, with emphasis given to younger subjects [96]. More convincing studies similar to these are encouraged, in order to help in the wider deployment of e-emergency systems.

In particular, the transmission of echography video in the monitoring of pre-hospital subjects in cardiac emergencies (such as, for example, using wireless LAN connections [66] and in trauma cases using satellite connections [62]) has been demonstrated in only a very limited number of cases. It is expected that the recent wide availability of portable ultrasound systems, the wide availability of 3G systems and beyond, and the further development of video systems will facilitate the spread of video systems, both for the transmission of ultrasound exams, as well as for the transmission of subject video and teleconferencing applications.

Concluding, it is expected that m-health e-emergency systems will significantly affect the delivery of healthcare. However, their exploitation in daily practice, as well as the monitoring and evaluation of these systems, still remain novel goals, yet to be achieved.

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