31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

An Overview of Recent Health Care Support Systems for eEmergency and mHealth Applications

E. C. Kyriacou, C.S. Pattichis, M.S. Pattichis

Abstract— **Advances in mobile communications and medical technologies facilitate the development of emerging mobile systems and applications for healthcare. The objective of this paper is to provide an overview and the current status of mobile health care systems (mHealth) and their applications for Emergency healthcare support (eEmergency). Our paper reports on journal papers that use wireless, emergency telemedicine systems that appeared since 2000. The majority of the applications are focused on the transmission of crucial biosignals (mainly ECG) for the support of heart-related healthcare. A limited number of new studies were focused on supporting emergency healthcare for trauma by facilitating both 2D image or video transmission (eg: ultrasound). Alternatively, new studies have focused on integrated systems for specialized emergency scenaria such as stroke. This paper is an extension of work previously published by our group [1].**

I. Introduction

The provision of effective emergency health care can prove essential for patient's recovery or even for a patient's survival. Examples include cases of cardiac-diseases or coronary artery diseases where thrombolysis is required and survival is related to the "call to needle" time, or cases of serious injuries spinal cord or internal organs trauma, where the way the incidents are treated and transported is crucial for the future well being of the patients. Here, eEmergency, mHealth systems can be defined as "emerging mobile communication systems for the support of emergency health care" [2].

Unfortunately, most emergency cases take place away from central hospitals and may have to be treated by non specialized personnel. The easiest way of supporting these people is through the use telemedicine. Recent advances in mobile communications are enabling the use of telemedicine systems at anywhere and at any time.

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 [1]. Moreover, an edited volume was published [2], 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), and an update to the above mentioned work.

The structure of the paper is as follows. Section II provides a brief summary of the wireless technologies used for m-Health systems. Section III presents examples of e-Emergency, m-Health systems, related to some specific applications of interest and Section IV provides future challenges and concluding remarks.

II. Wireless Transmission Technologies

Mobile telemedicine systems are based on different types of wireless technologies depending on their application field. In general, all systems are based on the following wireless technologies: Satellite links where a variety of data-transfer rates from 2.4 kbps up to 2x64kbps and beyond can be supported. They provide worldwide coverage enabling the use over the sea or in areas with no other infrastructure.

Mobile communication links include GSM, which is currently in use worldwide. GSM provides support of second generation (2G) mobile communication networks. 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. 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) with theoretical peaks up to 14.4 Mbps.

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. However WLAN coverage is limited up to a distance of about 100 meters per cell (access point). Ad-hoc networks are based on geographically distributed mobile nodes that interact 'on the move' with one another over a wireless medium instead of communicating wirelessly to a base station.

A detailed analysis of these wireless transmission technologies can be found in [1].

III. mHealth eEmergency Systems

Telemedicine applications appeared in literature 100 years ago [1]. Since then, many studies have been presented. Recent advances in mobile communications have also impacted mHealth eEmergency systems.

E.Kyriacou is with the Department of Computer Science and Engineering, Frederick University Cyrus, Lemesos, Cyprus (e-mail: e.kyriacou@frederick.ac.cy).

C.S.Pattichis is with the Department of Computer Science, University of Cyrus, Nicosia, Cyprus (e-mail: pattichi@ucy.ac.cy).

M.S.Pattichis is with the Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, USA (e-mail: pattichis@ece.unm.edu).

Table 1a. Selected applications of m-health e-emergency systems that use GSP/GPRS and 3G networks

Comm. 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.* [3]	00	√					Ambulance triage support
	Yan Xiao *et al.* [4]	00	√			√		Ambulance neurological examination support
	Reponen *et al.* [5]	00		√				Transmission of CT scans using GSM and PDAs. Images transmitted to a neuroradiologist for preliminary consultation
	Oguchi *et al.* [6]	01		√			√	Use of personal handyphone system to transmit CT images using a web based application
	Anantharaman *et al.* [7]	01	√					Pre-hospital support
	Rodriguez *et al.* [8]	01	√					Cardiac arrest treatment
	Istepanian *et al.* [9]	01	√	√				Transmission of ECG data and still images for emergency use. Compression of ECG using a wavelet compression method
	Pavlopoulos *et al.* [10]	01	√	√				Portable teleconsultation medical device
	Chiarugi *et al.* [11]	03	√					Transmission of 12-lead ECG in order to support ambulance and rural health centers emergencies (HygeiaNet)
	Kyriacou *et al.* [12]	03	√	√				Wireless transmission of biosignals and images from a Rural Health Center and a moving ambulance vehicle to a central hospital
	Hall *et al.* [13]	03			√			Wireless access to Electronic Patient Record
	Clarke *et al.* [14]	04	√					Wireless connection to sensors and transmission of data from an ambulance
	Salvador *et al.* [15]	05	√				√	Transmission of ECG and other parameters to support patients with chronic heart diseases
	Clemmensen *et al.* [16]	05	√					Transmission of ECG signals to a cardiologist's PDA to improve time to reperfusion
	Campbell *et al.* [17]	05	√					Wireless transm. 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.* [18]	06	√					Wireless transmission of 12-lead ECG from a moving ambulance vehicle to a central hospital
	Sillesen *et al.* [19]	06	√					Transmission of ECG signals to a cardiologist's PDA in order to improve time for PCI treatment
	Kontaxakis *et al.* [20]	06				√		Tele-echography system and 3D-ultrasound
	Lee *et.al.*[21]	07	√					Patient continuous monitoring/alert in case of emergency. Signals are transmitted through GSM and acquisition to device is through Bluetooth.
3G	Chu *et al.* [22]	04	√	√		√		Trauma care through transmission of patient's video, medical images and ECG
	Garawi *et al.* [23]	06				√		Tele-operated robotic system for mobile Tele-Echography (OTELO-Project)
	Tsapatsoulis *et al.* [24]	07				√		Coding of Region of Interest for transmission of video over low bandwidth
	Doukas *et.al.* [25]	08		√		√		Adaptive transmission of Medical Video and images using a Scalable coding and context aware scheme base on the case needs.
	Panayides *et al* [26]	08				√		Efficient H.264 coding of medical ultrasound video over wireless channels

A. Overview

We present a literature review for studies published in journals, related to mobile systems for emergency health care support (eEmergency, mHealth systems) that appeared since 2000. We restricted our literature review to articles that were available through Medline and the IEEE explore databases. Many of these papers were excluded due to the medical approach using existing systems. We had selected 35 papers presenting newly created systems table 1.

The papers are grouped using wireless technologies types: (i) GSM/GPRS, (ii) 3G, (iii) Satellite, and (iv) Wireless LAN/Ad-Hoc networks. The data transmitted are coded under the table column categories: "ECG and other biosignals", "IMG" for medical images or patients 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. Depending on the types of data transmitted, we have emergency applications related to triage support, heart failure or Coronary artery disease control, trauma support and support for special groups (e.g. children or the elderly).

For the first group, Mobile Telephony networks GSM/GPRS, we have the highest number of applications (19). These applications could be divided into two main categories, those transmitting 1-D biosignals such as ECG, oxygen saturation, blood pressure etc., and those transmitting 2-D medical images or simply pictures of a patient. We provide a summary of specific characteristics for

Table 1b. Selected applications of m-health e-emergency systems that use Satellite and Wireless LAN

Commun. Technol.	Author	Year	Data Transmitted				Web application	Comments
			ECG and/or other signals	IMG	EPR/ DATA	Video		
Satellite	Kyriacou *et al.* [12]	03	√	√				Wireless transmission of biosignals and images from a Rural Health Center and a moving ambulance vehicle to a central hospital
	Strode *et al.* [27]	03		√				Examination of trauma using focused abdominal sonography (military)
	Vieyres *et al.* [28], & Canero *et al.* [29]	05				√		Tele-operated robotic system for mobile Tele-Echography (OTELO-Project)
	Virgin Atlantic Airways [30]	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 \ AD HOC networks	Garrett *et al.* [31]	03				√		Echocardiogram transmission in cardiac emergency from an ambulance in transit to a tertiary care facility
	Nakamura *et al.* [32]	03				√		Wireless emergency telemedicine LAN with over 30 Km distance used in the Japan Alps used for mountain climbers emergency telemedicine
	Pagani *et al.* [33]	03		√			√	Web based transmission of cranial CT images. Comparison of the results
	Hall *et al.* [13]	03			√			Wireless access to Electronic Patient Record
	Lorincz *et al.* [34]	04	√					Sensor networks for emergency response, system tested using two vital signs monitors
	Clarke *et al.* [14]	04	√					Wireless connection to sensors and transmission of data from an ambulance Telecare project
	Maki *et al.* [35]	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
	Kim *et al.* [36]	05		√				Transmission of CT and MRI images through a PDA and wireless high-bandwidth net to neurosurgeons
	Campbell *et al.* [17]	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
	Lin *et.al* [37]	07	√					Wireless transmission of biosignals from elderly patients.
	Gao *et.al.* [38]	07	√					Transmission of biosignals using Ad Hoc networks in order to support Triage in cases of large disasters.
	Doukas *et.al.* [25]	08		√		√		Adaptive transmission of Medical Video and images using a Scalable coding and context aware scheme base on the case needs.
	Kim *et al.* [39]	09				√		Transmission of video and audio to consult acute stroke patients treatment

application.

The second group covers those applications that use 3G mobile networks. We mention two interesting applications. First, the introduction of 3G enabled the transimission of both biosignals and 2D images of the patient in [22]. In a more advanced application, the authors reported on the transmission of both biosignals and real time ultrasound video [23].

For satellite links; we have only found four new significant studies (since 2000). We do note however that a significant number of studies using satellite links were published prior to these studies (not reported here). An important application is the Virgin Atlantic press release [30] which announced the first wireless telemedicine system that will be adopted by a major airline carrier that will be available in all its flights.

The last category of applications covers the use of Wireless LANs and Ad-hoc networks. These applications are primarily focused on disaster control cases where many injured people might be concentrated in a small area and a network must be used in order to monitor and control many patients simultaneously.

IV. Concluding Remarks – Muture Challenges

This paper provides an overview of recently published wireless emergency healthcare systems. These systems clearly demonstrate the benefits and the need for their wider deployment. Even though, emergency telemedicine has been discussed for more than 100 years, the wide use of e-emergency systems is still lacking.

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: support in the adoption of policy and strategy for the development for e-health; advice on needs assessment and evaluation of eHealth services; information on best practice and trends; and advice on e-health norms and standards [40]. 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 remains an unattained goal, yet to be achieved.

REFERENCES

[1] E. Kyriacou, M.S. Pattichis, C.S. Pattichis et al. "m-Health e-Emergency Systems: Current Status and Future Directions," *IEEE Antennas and Propagation Magazine*, Vol. 49, No. 1, pp. 216-231, 2007.

[2] R..H. Istepanian, S. Laxminarayan, and C.S. Pattichis, Eds, *M-Health: Emerging Mobile Health Systems*, Springer, NY, 2006.

[3] R. Karlsten, B.A. Sjoqvist, "Telemedicine and decision support in emergency ambulances in Uppsala," *J. of Telemedicine and Telecare,* vol. 6, no. 1, pp. 1-7, 2000.

[4] Yan Xiao, D. Gagliano, M. LaMonte et.al. "Design and evaluation of a real-time mobile telemedicine system for ambulance transport," *J. of High Speed Networks,* vol. 9, no. 1, pp. 47-56, 2000.

[5] J. Reponen, E. Ilkko, L. Jyrkinen at al., "Initial experience with a wireless personal digital assistant as a teleradiology terminal for reporting emergency computerized tomography scans," *J. Telemed Telecare,* vol. 6, no. 1, pp. 45-9, 2000.

[6] K. Oguchi, S. Murase, T. Kaneko at al., "Preliminary experience of wireless teleradiology system using Personal Handyphone System," *Nippon Igaku Hoshasen Gakkai Zasshi,* vol. 61, no. 12, pp. 686-7, Oct. 2001.

[7] V. Anantharaman and Lim Swee Han, "Hospital and emergency ambulance link: using IT to enhance emergency pre-hospital care," *Int. J. of Medical Informatics,* vol. 61, no. 2-3, pp. 147-161, 2001.

[8] A. Rodrvguez, J.L. Villalar, M.T. Arredondo et al. "Transmission trials with a support system for the treatment of cardiac arrest outside hospital," *J. of Telemedicine and Telecare,* vol. 7,suppl. 1, pp. 60-62, 2001.

[9] R.S Istepanian, E. Kyriacou, S. Pavlopoulos et al., "Effect of wavelet compression on data transmission in a multipurpose wireless telemedicine system," *J. of Telemedicine and Telecare,* vol. 7, suppl. 1, pp. 14-16, 2001.

[10] S. Pavlopoulos, E. Kyriacou, A. Berler et al., "A novel emergency telemedicine system based on wireless communication technology – AMBULANCE," *IEEE Trans. Inform. Tech. Biomed.,* – Special Issue on Emerging Health Telematics Applications in Europe, vol. 2, no. 4, pp. 261-267, 1998.

[11] F. Chiarugi, D. Trypakis, V. Kontogiannis et al., "Continuous ECG monitoring in the management of pre-hospital health emergencies," *Computers in Cardiology*, pp. 205 – 208, 2003.

[12] E. Kyriacou, S. Pavlopoulos et. al., "Multi-purpose HealthCare Telemedicine Systems with mobile communication link support," *BioMedical Engineering OnLine,* http://www.biomedical-engineering-online.com, vol. 2, no. 7, 2003.

[13] E.S. Hall, D.K. Vawdrey, C.D. Knutson, and J.K. Archibald, "Enabling remote access to personal electronic medical records," *IEEE Eng. in Medicine and Biology Mag.*, vol. 22, no. 3, pp. 133-139, 2003.

[14] M. Clarke, "A reference architecture for telemonitoring," *Stud. Health Technol. Inform*., vol. 103, pp. 381-4, 2004.

[15] C.H. Salvador, M. Pascual Carrasco et.al., "Airmed-cardio: a GSM and Internet services-based system for out-of-hospital follow-up of cardiac patients," *IEEE Trans. Inf. Technol. Biomed.,* vol. 9, no. 1, pp.73-85, 2005.

[16] P. Clemmensen, M. Sejersten, M. Sillesen at al., "Diversion of ST-elevation myocardial infarction patients for primary angioplasty based on wireless prehospital 12-lead electrocardiographic transmission directly to the cardiologist's handheld computer: a progress report," *J. Electrocardiol.,* vol. 38, no. 4, pp. 194-8, 2005.

[17] P.T. Campbell, *et al.,* "Prehospital triage of acute myocardial infarction: wireless transmission of electrocardiograms to the on-call cardiologist via a handheld computer," *J. Electrocardiol.,* vol. 38, no. 4, pp.300-9, 2005.

[18] P. Giovas, D. Thomakos, O. Papazachou at al., "Medical aspects of prehospital cardiac telecare," in *M-Health: Emerging Mobile Health Systems*, R.H. Istepanian, S. Laxminarayan, C.S. Pattichis, Eds. NY: Springer, 2006, pp. 389-400.

[19] M. Sillesen, M.S. Ripa, S. Strange et al., "Telemedicine in the transmission of prehospitalisation ECGs of patients with suspected acute myocardial infarction," *Ugeskr Laeger*, vol. 168, no. 11, pp.1133-6, 2006.

[20] G. Kontaxakis, G. Sakas, and S. Walter, "Mobile Tele-Echography Systems – TELEINVIVO: a Case Study," in *M-Health: Emerging Mobile Health Systems*, R.H. Istepanian, S. Laxminarayan, C.S. Pattichis, Eds. NY: Springer, 2006, pp. 445-460.

[21] R.G Lee, K.C Chen, Chun.Chieh Hsiao et al., " A mobile Care System with Alert Mechanism," *IEEE Trans Inf. Tech. Biom.*, vol.11, no.5, pp. 507-517, 2007.

[22] Y. Chu and A. Ganz, "A mobile teletrauma system using 3G networks," *IEEE Trans. Inf. Technol. Biomed.,* vol. 8, no. 4, pp. 456-62, 2004.

[23] S. Garawi, R.S.H. Istepanian, and M.A. Abu-Rgheff, "3G wireless communications for mobile robotic tele-ultrasonography systems," *IEEE Communications Magazine,* vol. 44, no. 4, pp. 91-96, 2006.

[24] N. Tsapatsoulis, C. Loizou, and C. Pattichis, "Region of Interest Video Coding for Low bit-rate Transmission of Carotid Ultrasound Videos over 3G Wireless Networks," *in Proc. of IEEE EMBC'07,* Aug. 23-26, 2007, Lyon, France.

[25] C. Doukas and I. Maglogiannis, "Adaptive Transmission of Medical Image and Video Using Scalable Coding and Context-Aware Wireless Medical Networks," *EURASIP JWCN*, vol. 2008, Article ID 428397, 2008.

[26] A. Panayides, M. S. Pattichis, and C. S. Pattichis, "Wireless Medical Ultrasound Video Transmission Through Noisy Channels," in Proc. of IEEE EMBC'08, Aug. 28-30, 2008, Vancouver, Canada.

[27] C.A. Strode, B.J. Rubal, R.T. Gerhardt et al., "Wireless and satellite transmission of prehospital focused abdominal sonography for trauma," *Prehosp. Emerg. Care,* vol. 7, no. 3, pp. 375-9, 2003.

[28] P. Vieyres, G. Poisson, F. Courreges et al., "A Tele-Operated Robotic System for Mobile Tele-Echography: The OTELO Project", in *M-Health: Emerging Mobile Health Systems*, R.H. Istepanian, S. Laxminarayan, C.S. Pattichis, Eds. NY: Springer, 2006, pp.461-73.

[29] C. Canero, N. Thomos, G.A. Triantafyllidis et al., "Mobile tele-echography: user interface design," *IEEE Trans. Inf. Tech. in Biomed.,* vol. 9, no. 1, pp. 44-49, 2005.

[30] "Virgin to upgrade telemedicine across fleet," E-Health Insider, Available at: ;http://www.e-health-insider.com/news/item.cfm?ID=1925, Announced: 6, Jun. 2006.

[31] P.D. Garrett, *et al.,* "Feasibility of real-time echocardiographic evaluation during patient transport," *J. Am. Soc. Echocardiogr.,* vol. 16, no. 3, pp. 197-201, 2003.

[32] M. Nakamura, Y. Yang, S. Kubota et al., "Network system for alpine ambulance using long distance wireless LAN and CATV LAN," *Igaku Butsuri*, vol. 23, no. 1 pp. 30-39, 2003.

[33] L. Pagani, L. Jyrkinen, J. Niinimaki et al., "A portable diagnostic workstation based on a Webpad: implementation and evaluation," *J. Telemed. Telecare,* vol. 9, no. 4, pp. 225-9, 2003.

[34] K. Lorincz, D.J. Malan, T.R.F. Fulford-Jones et al., "Sensor networks for emergency response: challenges and opportunities," *IEEE Pervasive Computing,* vol. 3, no. 4, pp.16 – 23, Oct-Dec 2004.

[35] H. Maki, Y. Yonczawa, H. Ogawa et al., "A welfare facility resident care support system," *Biomed Sci Instrum.*, vol. 40, pp. 480-3, 2004.

[36] D.K. Kim, S.K. Yoo, S.H. Kim, "Instant wireless transmission of radiological images using a personal digital assistant phone for emergency teleconsultation," *J. Telemed. Telecare,* vol. 11, no. 2, pp. S58-61, 2005.

[37] B.S. Lin, B.S. Lin, N.K. Chou et al., "RTWPMS: A Real-Time Wireless Physiological Monitoring System," *IEEE Tarns. Inf. Tech. Biom.*, vol.10, no.4, pp. 647-656, 2006.

[38] T.Gao, T.Massey, L.Selavo et al., "The Advanced Health and Disaster Aid Network: A Light-Weight Wireless Medical System for Triage," *IEEE Trans. Inf. Tech. Biom.,* vol.1, no.3,pp. 203-216, 2007.

[39] D.K. Kim, S.K.Yoo, I.C.Park et al., "A mobile telemedicine system for remote consultation in cases of acute stroke," *J. Telemed. Telecare,* vol. 15, pp. 102-107, 2009.

[40] *eHealth Tools and Services, Needs of the Member States,* Report of the WHO Global Observatory on eHealth, WHO, Switzerland, 2006.