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Establishing Telemedicine System to Support Urgent Incidents around the borderline of Greece: Implemented Architecture and Evaluation

George J. Mandellos, George V. Koutelakis, Theodor C. Panagiotakopoulos, Andreas M. Koukias, Nomikos B. Mouzourakis, Michael N. Koukias, and Dimitrios K. Lymberopoulos, *Member, IEEE*

***Abstract*— An evaluation of a wide area Telemedicine System (TS) designed for a country with singular geomorphology like Greece is presented. It targets to improve the outcome in emergency cases, by means of an early and specialized pre-hospital treatment. The TS makes use of modern technologies leading to the cooperation of 30 mobile medical units, 3 Telemedicine Coordination Centers and 7 Regional Teleconference Rooms. An adaptive protocol is used to reduce the data transmission time and the resources required for archiving. An automated network switching keeps the communication live in most cases while a telemedicine service co-ordinates all the co-operating endpoints, providing call and connection management, remote healthcare assistance, teleconference capabilities and real-time vital signs' transmission.**

I. Introduction

Older studies [1] have supported that the early and specialized pre-hospital patient's management during emergency cases leads to the patient's survival. In cases, like heart diseases, serious head injuries, internal organs trauma, the handling, initial treatment and transportation is crucial.

Greece is a country with high death rate due to car accidents. Most of them take place far away from any healthcare institute. As a result, the response times to the beginning of the injured person treatment, are very long. Concerning the heart diseases, the death rates are also very high. A high patient's percentage (almost 70%), dies during transportation towards a hospital. Generally, there are various types of incidents (car accidents, patients suffering from heart diseases, pneumonics, several injuries etc.). Each incident needs different treatment and is required a different collection of diverse vital signs and other related information, in order an expert to determine the condition of the transported patient to the healthcare institute.

In most cases, the delay in administering the appropriate therapy to patients [2] is caused by reasons such as: The patient's lack of the ability to evaluate his symptoms and seek emergency care when needed; The pre-hospital evaluation and transport time; The in-hospital time that is needed for an expert to exact the correct diagnosis and begins the treatment. A rapid response time in pre-hospital actions concerning emergency heart deceases, decreases mortality and improves patient outcome [3]-[6].

Greece is a country with bold terrain relief (less low lands, many mountains) and a big number of islands. In many cases it is difficult for a patient in case of a health symptom to access a health care unit. In some cases it has also observed that the common telemedicine systems fail to communicate with their reception center due to lack of a communication signal or due to overloaded communication network.

This paper presents the design and evaluation of a new telemedicine system enabling ambulance staff, rescue people, emergency paramedics, or general practitioners, to collaborate in order to face pre-hospital patient treatment. It also permits the collaboration of more doctors in an educational scheme on an incident (on-line or offline). The TS covers up to 30 Mobile Units (MU), 3 Telemedicine Coordination Centers (TCC), 7 Regional Teleconference rooms (RTR) and is distributed in a large area of Greece including many places near borderline. This system has basic design characteristics [7] like: An automated switching between available communication media in case of

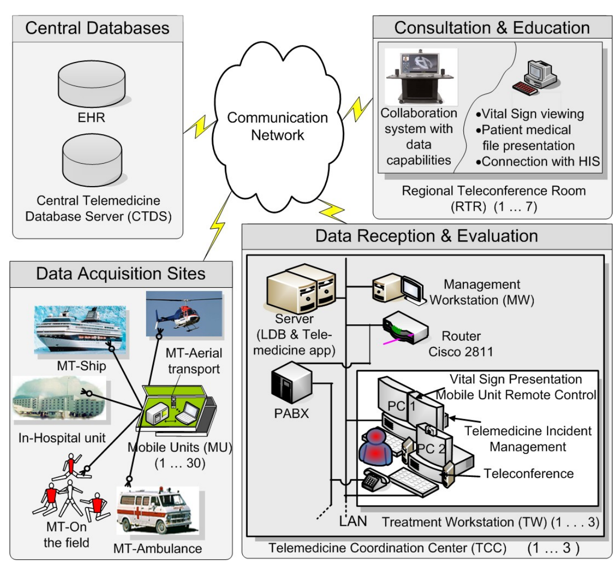

Fig. 1. Structure of the designed Telemedicine Service (TS).

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G. J. Mandellos, G. V. Koutelakis, T. C. Panagiotakopoulos, A. M. Koukias, N. B. Mouzourakis, M. N. Koukias and *D. K. Lymberopoulos are with the Wire Communication Laboratory, Electrical & Computer Engineering Department, University of Patras, GR 265 04 Panepistimioupoli - Rion, Greece, phone: +30-2610-969602; fax: 30-2610-996185;emails:mandello@upatras.gr,gkoutelakis@wcl.ee.upatras.gr,teop@wcl.ee.upatras.gr,koukiasa@upnet.gr,mouzmike@hotmail.com,koukias@wcl.ee.upatras.gr,dlympero@upatras.gr.

communication failure in borderline of Greece; A telemedicine service offering synchronization of multiple co-operating endpoints during an incident (regardless of the end-points' location and the networks quality) during real-time vital signs' transmission and teleconference; A distributed database system interacting with an Electronic Health Record (EHR) system.

This paper analyzes the architecture and the general use case scenario of the presented TS, illustrates the special handling of the connection establishment in difficult communication circumstances and evaluates the system functionality in real conditions' scenarios.

The proposed TS is a result of a coordinated by the Greek Information Society and the Greek Ministry of Defense.

II. Implemented Telemedicine System

A. System Architecture & General Use Case Scenario

The implemented system consists of four main parts (Data Acquisition Sites and Data Reception & Evaluation, Central Databases and Regional Teleconference Room, illustrated in Fig. 1. The main parts of the system communicate via a Virtual Private Network (VPN) dedicated for the TS. VPN ensures the security of data exchanging.

Moving Transports (MTs) (ambulances, ships, planes, etc.) which comprise the data acquisition sites, arrive at the area of incident to provide the urgent medical treatment and transfer the patient to the hospital. MTs are equipped with MUs, which include a Medical Monitor (MM) (for vital signs' acquisition), a portable Personal Computer (PC) with proper software, communication terminal devices of diverse networks and a wireless camera (for still images and patient video). The MM of each MU is able to acquire vital signs, such as electrocardiogram (ECG), Blood Oxygen Saturation (SPO2), Non Invasive Blood Pressure (NiBP) and Temperature (Temp) from patients and transmit them via diverse network types, to the Telemedicine Coordination Centers (TCCs). Data regarding the patient and the medical incident can be collected on the field where an incident takes place or on route to the hospital and transmitted to the TCC.

The whole operation is controlled by the TCCs, which accomplish data reception and evaluation. TCCs are located at the central hospitals and support MTs. A TCC facilitates proper network devices, a Management Workstation (MW), three Treatment Workstations (TWs) as well as a Server hosting the Local DataBase (LDB) for storing all the incident data. When a call arrives at the TCC, optical and sound alerts are enabled at the MW to inform for the data arrival. MW selects a TW in order to handle the incident. Several options are activated when a connection is established such as call handover between workstations of the same TCC, establishment of a new connection between a MT and a RTR for observation purposes as well as disengagement of an already established connection.

The TW provides the functionality needed to carry out an incoming call - incident - from a MT. When a TW is assigned an incoming call, all the data including patient's demographics, incident's data, and still images, provided by the MT are displayed. After the completion of a patient identification process, the vital signs view is enabled and the physician is able to watch the acquired vital signs. Vital signs monitoring is enabled only when both the MU of an MT and a TW of the TCC participating in the same connection are connected on a proxy server (software component located at the Server). Proxy server starts multicasting, retaining the synchronization between all the participating endpoints. Multicasting targets the MU, TW and any possible participating RTR. The multicast is continued until the MU participating in the handled connection disconnects. Both MT's paramedics and TCC's physicians send to each other medical reports in a collaboration way. All the decisions regarding the pre-hospital actions are made by the physician and passed to the MT's stuff via the proxy server. Then MU requests a connection termination and the TCC disengages the connection. After the disengagement, all the data regarding patient and handled incident are stored in the LDB and sent to the Central Telemedicine Database Server (CTDS) through HL7 messages.

TW is also able to establish teleconference with the MU. Moreover, through the call management application, TCC's administrator is able to connect via teleconference any MU, currently connected with the TCC he is located, with any RTR. RTRs' role is active in teleconsultation procedures. However, they cannot interfere with the processing of the incident and vital signs. Regarding the incident treatment, their role is the observation and consulting. The teleconference is activated only when the bandwidth is efficient. Vital signs transmission happens first, before any other service offered by the designed telemedicine system. According to the range of the remaining bandwidth (it depends on the media of the active network connection), text, audio or video teleconference can be used.

The incident data are stored in the LDB of the called TCC. A CTDS is designed to keep the records of the patients and the basic attributes of incidents. However, the whole content of an incident is stored in the LDB of the TCC that handled it. Inside the CTDS, a reference link connects user to the proper TCC, which keeps the whole incident data. CTDS communicates with an Electronic Health Record (EHR) via a suitable proxy server exchanging the appropriate HL7 messages. CTDS can either update the EHR for possible changes to data regarding already registered patients or register new patients to the EHR.

B. Connection Establishment Handling

Each MU is able to establish a connection with a TCC via multiple types of networks. The designation of the network to be used is based on the network availability and the network's available resources. Accordingly, the following hierarchy is used: ADSL, mobile 3G, ISDN, dial-up and finally satellite. The bandwidth of each network varies, depending on the bandwidth offered by the provider and the current network traffic. Initially, the MU identifies the available networks through the connected network cards. Then, a network is automatically selected using the aforementioned hierarchy and a connection with the TCC is established.

In the course of a telemedicine incident, many factors such as low signal strength can result in a disconnection from the designated network. A connection loss acknowledgement is usually obtained with an average delay of 1-3 sec and a maximum delay of 5 sec by Windows XP x86. When the MU detects the network disconnection, the default PC gateway is modified, establishing connection with the network determined by the network hierarchy list. If no other network is available, reconnection with the same network is repeatedly attempted every 10 secs.

Vital signs are collected constantly from different threads in the course of an incident and are transmitted in the form of appropriately sized packets every 5 seconds. It is obvious that a a loss of the connection between the MU and the TCC can result in a temporary halt in transmission of vital signs. If the disconnection occurs at the beginning of the time slot between two packet transmissions and an immediate reconnection takes place, it will be seamless to the TW user and the vital signs viewing will not be interrupted.

However, it is more likely that the reconnection will not have been achieved until the end of the time slot. This can result in loss of one or more packets and void viewing of vital signs. The number of these packets depends on the time elapsed until reconnection with another or the same network occurs. In this case, the MU marks these packets and keeps on transmitting the most recent vital signs, as soon as the connection with the TCC is restored. In order to maintain real-time communications, the marked packets are transmitted and become available to the TW, after all real-time vital signs have been transmitted.

An estimation of the time period, during which the vital signs viewer remains idle (T_{idle}), due to the loss of connection with the MU, is extracted by the following calculation:

$$T_{idle} = ((T_{off}+T_{pack}) \text{ div } (T_{pack}))*T_{pack}$$

T_{off}: time period from the first vital signs packet transmission failure to a network connection reestablishment
T_{pack}: time period needed for collecting and transmitting a single vital signs packet.

Conclusively, if the MU has a redundant network available, a connection loss can result in void periods during the vital signs viewing with a maximum duration of one Tpack, whereas the absence of a redundant network can potentially result in a much longer void, as it was estimated previously.

III. Evaluation

The pilot project was examined with all MU's installed. For a period of 3 months, a total of 53 examinations (patients) were serviced by 17 MU's (of 30) located in ambulances. The collected data were transmitted to the 3 TCCs operated by 3 administrators and 12 doctors. Medical stuff watched each session in the 7 RTRs.

Doctors and administrators were taught by three (3) day seminars (system demonstration and usage) that were locally organized on each TCC and later through the help desk that was established. MUs users were taught on site in parallel with MUs installation process. In certain difficult cases (e.g. software updates) on site visits were carried out. Doctors, administrators and MU users will be mentioned as users.

The adopted evaluation methodology [8] was divided in three steps. At first, the user remarks were rated by recording their comments during the supplied seminars [7]. Then, the comments during calls to the help desk were recorded. Finally, after a period of system's usage, the users were requested to fill in appropriate structured questionnaires. The questionnaires consisted of 68 questions divided in the following categories: System characteristics; Patient data; Information representation/query; Graphical representation subsystem; Used terminology/Error messages/Help; System learning; Communication with other systems/users; Overall system appreciation; General questions/personal data.

Tables I, II, III and IV present some sample answers on the supplied questionnaires as a percentage of negative (-2,-1), neutral (0) and positive (1, 2) answers per question.

During the period of the system pilot operation we also tested the system convenience and reliability. Figure 2 shows the average time regarding the vital sign acquisition, transmission and interpretation. Depending on the patient's state and patient's cooperation, a paramedic needs about 2 min to connect all the needed sensors for 7-lead ECG, SPO_2, Temp, and NiBP acquisition. A mean time of 50 sec was required for the mobile connection establishment, the patient identification and the vital signs' transmission to the TCC.

Depending on the MT speed, the average time for the patient transportation was 30 min. Therefore, the MT was arrived to the hospital 27 min and 10 sec after the start of vital sign transmission. Doctors need approximately 12 min to accomplish the ECG interpretation and the other vital signs' evaluation. Thus, the diagnosis and the initial treatment for the incident could be made 15 min and 10 sec before the patient's arrival to the hospital. A proper hospital reception of the patient could be prepared during this time. Without the TS, the treatment begins at least 42 minutes later (transportation, interpretation, in-hospital handling, etc) that is a crucial time, able to affect the patient's outcome.

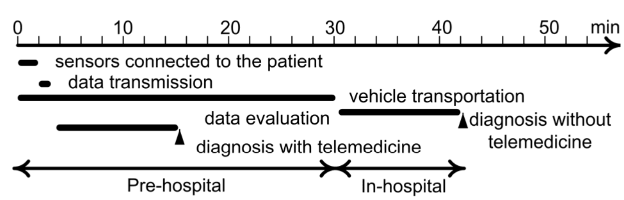

Fig. 2. Mean required time for pre-hospital and in-hospital actions

Regarding the success of connection attempts, 37 of 53 cases were successful at the first try. A second or third try was required in 11 and 5 cases respectively. In a total of 53 cases, 40 cases were transmitted on the first try, 11 were interrupted and retransmitted once and 3 were interrupted twice or more times. The most common reason for the transmission failure was the low signal of the mobile 3G card in some geographical areas, due to geomorphology and lack of available network connections for the specific situation, other than mobile 3G.

TABLE I
% RATES ON SYSTEM'S GENERAL CHARACTERISTICS

	(-2)+(-1)	(0)	(1)+(2)
System's reliability: error frequency	0	15	85
System's resource management	3	19	78
System's customization	0	53	47

TABLE II
% RATES ON INFORMATION DISPLAY/SEARCH/RETRIEVAL

	(-2)+(-1)	(0)	(1)+(2)
Search / Retrieval Time	3	7	90
Grouping of similar information	0	3	97
Information amount	0	22	78
On-screen information placement	0	3	97
Window's sequence	0	6	94

TABLE III
% RATES ON SYSTEM'S LEARNING

	(-2)+(-1)	(0)	(1)+(2)
General the system learning process	0	9	91
The advanced functions learning	0	9	91
The total required learning time	0	6	94
Exploratory learning of the system?	0	6	94
Required actions to complete a task	0	6	94

TABLE IV
% RATES ON OVERALL SYSTEM'S EVALUATION

	(-2)+(-1)	(0)	(1)+(2)
Total Appreciation	0	31	69
Satisfaction using the system	3	34	63
Does the system motivate the users?	6	28	66
The use of the telemedicine system	0	28	72

The MUs' advantage was that in both cases (no connection with the first try or interruption during the data transmission), no data loss was observed, because all of the collected data from the system startup till the transmission were stored locally in the MU, in order a complete medical report to be available every time.

IV. DISCUSSION AND CONCLUDING REMARKS

Due to geomorphology of Greece and the big number of islands we implemented a complicated telemedicine system in order to overcome problems, such as the frequent interruptions of connections, the low signal level, the entire lack of signal in some regions, or the connection disability due to the overloaded communication networks. The implemented system is designed to support multiple communication networks, in order to be able to proceed with the automated switching between networks when the signal level of the active network goes below a predefined threshold. Furthermore, appropriate synchronization algorithms have been used, to ensure that all communicating endpoints are viewing the same real time exchanged data. An adaptive protocol e-SCP-ECG$^+$ [9] have also been used in order to reduce the transmitted information volume. e-SCP-ECG$^+$ enhances the functionality of simple SCP-ECG embedding an enhanced medical dataset. The use of e-SCP-ECG$^+$ ensures the data integrity.

The system's evaluation process has indicated that endpoints can be repeatedly connected to and disconnected from an already established session, without disturbing the other parties of the session. Any endpoint can be added in an active session, whenever it sends a request, gaining the ability to observe the incident handling procedure while having the ability to provide feedback through teleconference.

Fig. 2 depicts that the time required for pre-hospital and in-hospital actions satisfies the target of the implemented system, since doctors are able to make an initial diagnosis before patients arrive at the hospital, enabling a proper preparation for the patients' in-hospital treatment.

In a future work the comprehensive data relative with critical packets losses, endpoint reconnection times in relation with the communication networks state and availability e.t.c. will be recorded.

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