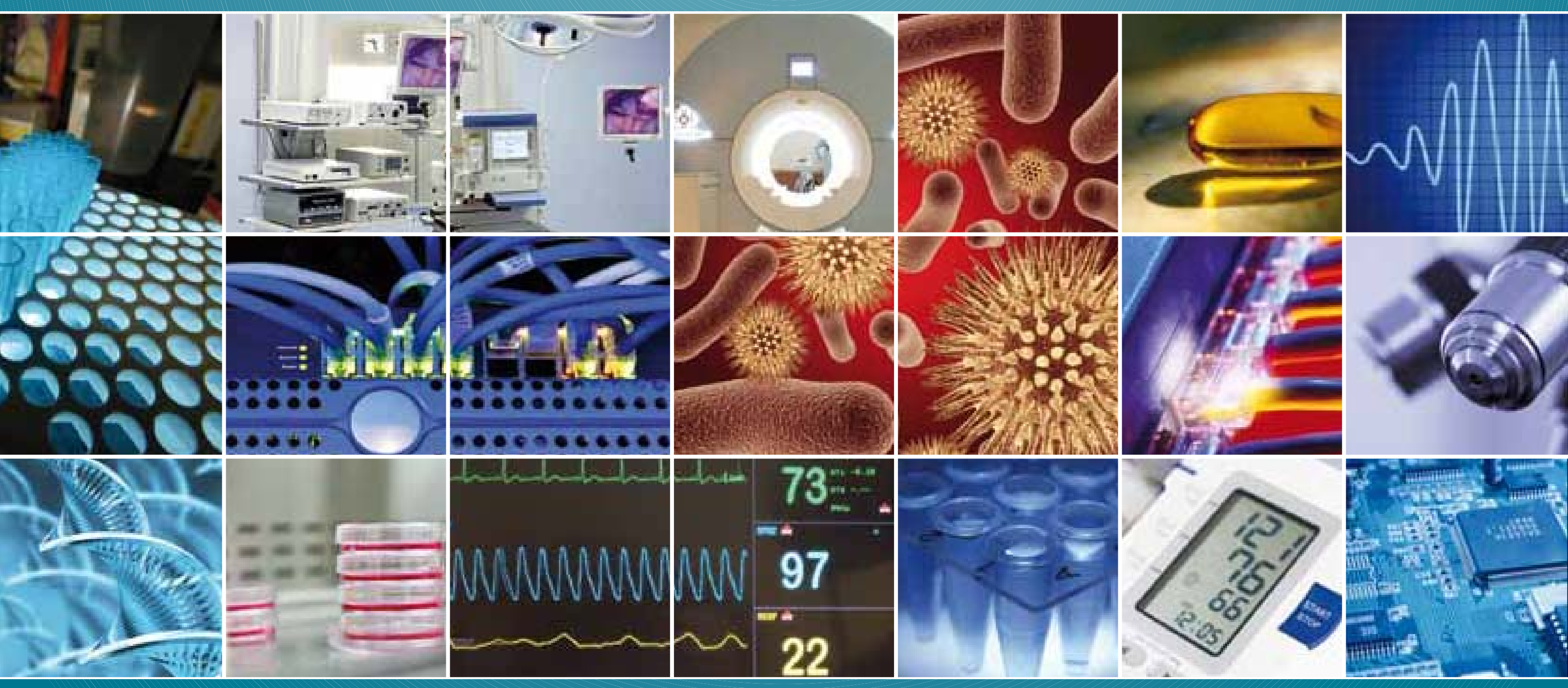
International Journal of Telemedicine and Applications

Healthcare Applications and Services in Converged Networking Environments

Guest Editors: Tasos Dagiuklas, Maria G. Martini, Athanasios Demiris, and George Anastassopoulos



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Editorial Board

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 649597, 2 pages
doi:10.1155/2010/649597

Editorial

Healthcare Applications and Services in Converged Networking Environments

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Received 31 December 2010; Accepted 31 December 2010

Next generation wireless and wireline communication technologies for healthcare applications and services is a new and growing field to facilitate reliable, innovative, personalized, and high-quality healthcare applications and services. Advances in networking infrastructures (e.g., *HSxPA/WiMax/LTE*) are important in order to deliver healthcare applications and services regardless of the patient's physical location. Furthermore, continuous and personalized care solutions address the participation of patients in care and prevention processes and respond to the needs of elderly people by using sensors and advanced wireless monitoring tools. Finally, another area where the use of next generation communication technologies may foster rapid developments in healthcare is the support of the translation of cutting-edge research into clinical practice.

The goal of this special issue is to report on cutting-edge research in converged communications and networking solutions for healthcare. Basic research papers were solicited, together with papers on systems integration or deployment, reflecting those aspects of research in communications for healthcare which are distinctly different from communications research in general.

The call for papers for this special issue attracted numerous responses from the research community, and submissions covered diverse areas of interest. After an extensive peer review process, nine papers have been selected for inclusion in this special issue, addressing requirements for e-Health services and applications, technologies and systems for telemedicine applications, and pilot implementations of telemedical systems. Several application areas have been addressed, ranging from cardiology to neurology and chronic pulmonary diseases, besides general purpose telemedicine platforms. In the following paragraphs, we briefly introduce the papers.

The article "*Using exploratory focus groups to inform the development of targeted COPD self-management education DVDs for rural patients*" by M. Stellefson et al. assessed the self-management learning needs, experiences, and perspectives of COPD patients treated at a Certified Federal Rural Health Clinic to inform the development of a COPD self-management DVD. Engaging rural communities in formal qualitative inquiries to describe COPD specific needs may lead to future use of educational technologies aimed at improving quality of life for rural populations.

The article "*e-SCP-ECG+ protocol: an expansion on SCP-ECG protocol for health telemonitoring—pilot implementation.*" by G. C. Mandellos et al., extends the use of SCP-ECG protocol in order to be included in health monitoring systems by introducing new sections into SCP-ECG structure for transferring medical and comprehensive demographic data. It also considers the pilot implementation of the new protocol as a software component in a Health telemonitoring system.

The article "*Implementation of compressed sensing in telecardiology sensor networks,*" by E. C. Pinheiro et al., presents an implementation of a compressed sensing paradigm in a wireless sensor network. The cardiovascular function monitoring was assessed and found to be very profitable. It was found that the approach between the two distant worlds of wireless sensor networks and compressed sensing is very interesting and may be further transposed to other areas of patient monitoring.

The article "*An empirical analysis of the current need for teleneuromedical care in German hospitals without neurology departments*" by G. W. Ickenstein et al. delivers an excellent example of the high value in the use of next generation communication technologies to address the lack of highly specialized expertise in rural areas. The article describes the need for setting up teleneurology infrastructure in order to support small hospitals in rural areas when treating patients with strokes and other acute conditions or syndromes urging for neurological or neurosurgical intervention. A large study in 119 acute hospitals without neurology departments in smaller towns in Germany (less than 100,000 inhabitants) clearly shows that the introduction of teleneurology is expected to increase quality of care and dicrease the need for unnecessary patient transports among other advantages.

The article "*Tile-Ippokratis: the experience of an ehealth platform for the provision of health care services in the island of Chios and Cyprus*" by H. Papadopoulos presents an integrated low-cost and ease-of-use ehealth platform for the provision of ehealth services for both patients with chronic diseases and patients who have been served by an intensive care unit. The platform based on the use of terrestrial and wireless communication infrastructures, supported teleconsultation and ehealth service.

The article "*Vascular neurology nurse practitioner provision of telemedicine consultations*" by B. M. Demaerschalk et al. investigates the possibility of delivering timely consultations in cases of acute stroke patients in emergency departments of rural areas within established hub and spoke networks. The study investigated the delivery of diagnosis and treatment both in terms of quality of diagnosis and treatment as well as overall duration of the procedure, clearly indicating that there is high value in telestroke consultations.

The article "*Telemedical support in patients with chronic heart failure: experience from different projects in Germany*" by A. Müller et al. addresses the very important application of telemedical monitoring in cases of chronic heart failure by reviewing seven related projects in Germany. The article emphasizes on the need for standardization, especially in order to be able to compare different telemonitoring solutions. Each of the projects addressed introduces a different approach in capturing and improving the situation of the affected patients, and the authors present these aspects for each one of the projects.

The article "*Flexible macroblock ordering for context-aware ultrasound video transmission over mobile WiMAX*," authored by M. G. Martini and C. T. E. R. Hewage, focuses on the exploitation of the characteristics of emerging network technologies and of recent coding standards for the joint design of the compression and transmission strategy in a telemedical system for real-time delivery of ultrasound video sequences.

The article "*Analysis of QoS requirements for e-Health services and mapping to evolved packet system QoS classes*" by L. Skorin-Kapov and M. Matijasevic provides a framework for the provisioning of 3 GPP network architectures. It proposes a mapping of e-Health service types to standardized 3GPP QoS class identifiers in the evolved packet system (EPS).

In summary, this special issue includes papers that span diverse areas of interest including system development and specific e-Health applications, as well as technological foundations.

The first two articles address requirements for eHealth services. Two articles address telemedicine technologies and systems. Finally, a group of articles describe telemedicine pilot implementations.

Acknowledgments

Besides the authors, we would like to thank the reviewers, who provided us with extensive and constructive reviews: thanks to them it was possible to run a special issue of such a broad scope. Last, but not least, the publishing staff provided a very effective support for this special issue. We would like to express our sincere gratitude to them all.

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 916868, 10 pages
doi:10.1155/2010/916868

Research Article

An Empirical Analysis of the Current Need for Teleneuromedical Care in German Hospitals without Neurology Departments

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Received 2 November 2009; Revised 21 March 2010; Accepted 25 May 2010

Academic Editor: Athanasios Demiris

Indroduction. At present, modern telemedicine methods are being introduced, that may contribute to reducing lack of qualified stroke patient care, particularly in less populated regions. With the help of video conferencing systems, a so-called neuromedical teleconsultation is carried out. *Methods*. The study included a multicentered, completely standardized survey of physicians in hospitals by means of a computerized on-line questionnaire. Descriptive statistical methods were used for data analysis. *Results*. 119 acute hospitals without neurology departments were included in the study. The most important reasons for participating in a teleneuromedical network is seen as the improvement in the quality of treatment (82%), the ability to avoid unnecessary patient transport (76%), easier and faster access to stroke expertise (72%) as well as better competitiveness among medical services (67%). The most significant problem areas are the financing system of teleneuromedicine with regard to the acquisition costs of the technical equipment (43%) and the compensation for the stroke-unit center with the specialists' consultation service (31%) as well as legal aspects of teleneuromedicine (27%). *Conclusions*. This investigation showed that there is a high acceptance for teleneuromedicine among co-operating hospitals. However these facilities have goals in addition to improved quality in stroke treatment. Therefore the use of teleneuromedicine must be also associated with long term incentives for the overall health care system, particularly since the implementation of a teleneuromedicine network system is time consuming and associated with high implementation costs.

1. Introduction

Stroke patients should be medically treated in specially designed facilities, so-called stroke units, because of the high efficacy of the care provided there [1] and recommended by the "European Stroke Initiative (EUSI)" as well as that of the "German Stroke Society (DSG)" [2]. In Germany, a total of 195 stroke units has been set up so far, enough to provide care for approximately half of all stroke patients in Germany. An increase in the number of stroke units to 250 has been planned in order to bring this effective care to almost 85% of stroke patients on the long-term [3]. However, acute care will continue to be provided in hospitals without stroke units in the future, especially in rural areas, where economic and staff limitations prevent the establishment of specialized neurological stroke units [4].

The question then arises, whether the use of modern teleneuromedicine methods could contribute to reducing the deficit in stroke patient care, particularly in less populated regions. In these areas, which lack neurological expertise, acute medical treatment of stroke patients usually occurs in the internal medicine department [5, 6]. Within the context of teleneuroconsultation, discussion and deliberation between two or more doctors regarding the best diagnostic and therapeutic approach for the acute stroke patient can

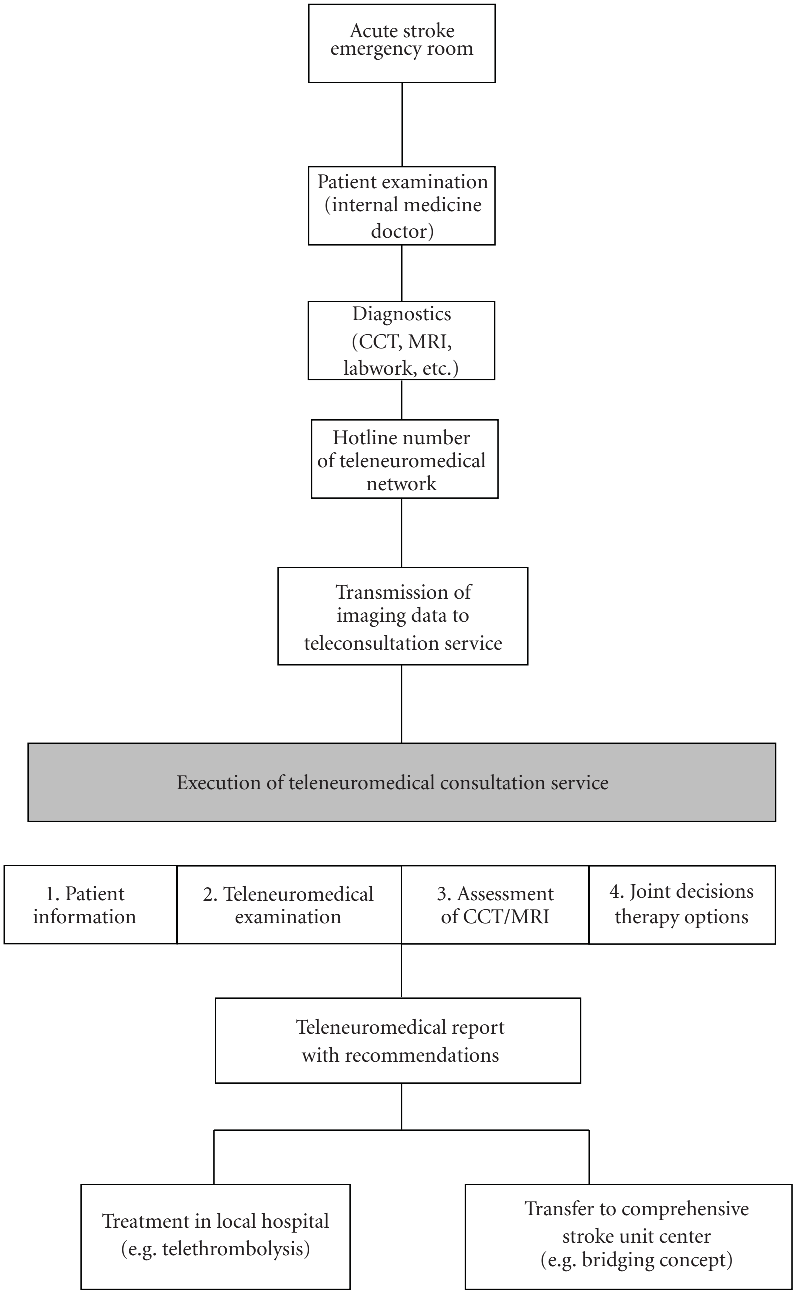

Figure 1: Sequence of events in teleconsultations in a teleneuromedical network [8, 9].

take place. In teleneuromedical settings, the stroke expert is connected by video and sound transmission, observing the examination of the patient, which is carried out by the doctor at the regional hospital [7].

In addition, the radiological image data (CT or MRI) collected in the regional hospital is electronically transmitted to a server platform that can be accessed by the stroke expert. On the basis of this information as well as the clinical impressions that the stroke expert receives during the video conference, the remote diagnosis and related therapeutic instructions or recommendations are determined and communicated to the doctor with a datasafe consultation sheet (see Figure 1) [8]. The study considers to what extent hospitals in Germany have already fulfilled the requirements for participation in a telehealth care network and to what extent these methods are already in use in Germany. Furthermore, an empirical analysis evaluates the advantages and disadvantages of teleneuromedicine. Finally, the findings of the investigation are discussed in relation to existing teleneuromedical networks and questions are answered as to what demands these special networks can meet in the future.

2. Methods

The study included a multicentered, completely standardized survey of physicians in hospitals by means of a computerized online questionnaire. Those selected for the investigation received an E-mail letter inviting them to participate. It contained information regarding the purpose and goal of the empirical analysis. It also included a link to an internet site where participants could fill out the questionnaire. In the analysis of the data, descriptive statistical methods were used. Both univariate (bar graphs and pie charts) and bivariate (crosstabulation) methods were used in the analysis according to GCP guidelines (EK 255102007).

Of a total of 2,104 hospitals in Germany, university hospitals, specialized hospitals and facilities with stroke units in a neurology department were excluded. Information regarding each hospital equipment and configuration was taken from their internet sites. This selection reduced the total by 845 to be 1,259 hospitals, constituting the basic population of the survey. However, not all of them could be reached on-line, since in 494 cases the hospital e-mail address was not available. Therefore, a total of 765 hospitals were surveyed (61%) and 346 (45%) hospitals could be directly reached with a general address in the hospital (i.e., info@...). Out of the 765 hospitals that fulfilled the inclusion criteria, 134 hospitals entered the website and completed the survey, amounting to a return rate of 18%. Out of the 134 participating hospitals, 15 had in addition to an internal medicine also a newly opened neurology department. These facilities also did not meet the inclusion criteria for the empirical analysis and were not included in the final analysis. The following descriptions and evaluations thus refer to 119 acute hospitals without any neurology department.

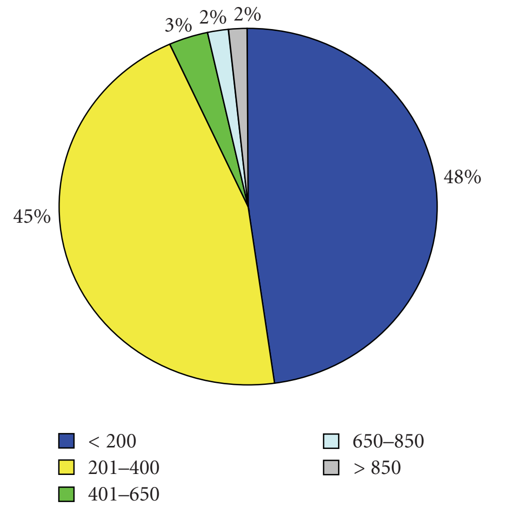

Figure 2: Size of hospitals according to number of beds.

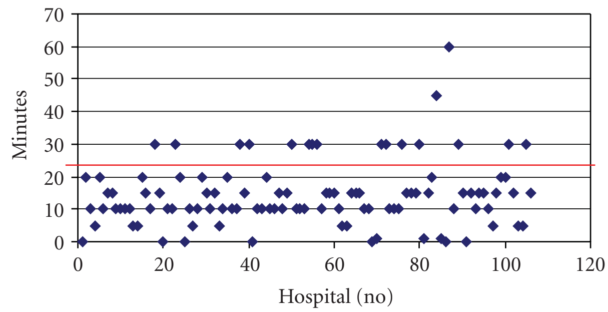

Figure 3: "Time to CT" for each hospital with a cut-off time at 25 minutes.

3. Results

As shown in Figure 2 predominantly hospitals with less than 200 beds (48%) or between 200–400 beds (45%) in small towns (5,000–100,000 inhabitants) took part in the survey (80%). 15% of the remaining participants belonged to the category "big city" (>100,000 inhabitants) and 5% to "rural regions" (<5,000 inhabitants). Regarding the current status of teleneuromedicine in hospitals without neurology departments, 36% of the responding hospitals are already connected to a teleneuromedical network and 14% of the participants are in negotiations with a stroke unit, whereas 30% plan to become active in telemedicine stroke treatment in the future. For only 11% of the participating hospitals telemedicine does not seem an option, while 8% did not answer this question.

The availability of an hospital network with high transmission speed is queried. In addition to these specific technical requirements, certain organizational conditions must be fulfilled in order for a hospital to take part in a teleneuromedical program. According to recommendations by the German Neurological Society (DGN) the time period from the arrival of the patient in the emergency room of the cooperating hospital to the beginning of the diagnostic phase should be no longer than 25 minutes ("Time to CT"). Therefore the distance between the emergency room and the location of the imaging center within the cooperating hospital is an important factor. Besides fast and easy access it is also required that the CT can be performed at any time 24 hours/7 days. The arithmetic mean of the responses "Time to CT" was 14.42 minutes with a median of 12.50 minutes and a standard deviation of 9.95 minutes. 17 participants (16%) could not comply with the required time period (see Figure 3).

In 114 of the participating hospitals (96%), the performance of a CT is possible, only 4% cannot meet this requirement. The DICOM interface needed for the CT image server exchange constitutes a critical component. 82% (94/119) reported that their CT meet this requirement but different possibilities for remote data transmission are used (see Table 1). Networking connectivity was possible in 85% (101/119) of the hospitals with different transmission speeds performed: <100 MB/s in 3%, 100 MB/s in 28%, 1 GB/s in 7%, >1 GB/s in 8%, and answer "not sure but >100 MB/s" in 39%.

In case of complications (e.g., malignant brain edema or intracerebral bleeding) associated with thrombolytic therapy, the transfer of a stroke patient to a neurosurgery department may be necessary. Moreover, for bridging concepts

Table 1: Technical possibilities for remote data transmission in networking hospitals [10].

Network access	Transmission speed	Suitability for teleneuromedicine	Costs
ISDN (point-to-point)	64–128 KB and more	(i) Nationwide, also available in rural areas (ii) Relatively slow (iii) Only for small image transfers (iv) Ability to bundle cables	24 euro per month and 128 KB
ADSL (Internet)	128–768 KB (upload) 1–16 MB (download)	(i) Fast downloading (ii) Not available everywhere (iii) Home connection	20–150 euro per month including connection costs
SDSL (Internet)	512 KB to 2 MB (upload and download)	(i) Fast Up- and downloading (ii) Not available everywhere (iii) Suitable for small and mid-sized hospitals	120–180 euro per month including connection costs
Satellite (Internet)	1,5 to 24 MB (download no upload)	(i) No upload → ISDN as feedback channel (upload) required (ii) Available everywhere (iii) Badly suited for synchronous connection because of long latency periods	30–130 euro per month according to provider and rate
Leased line SFV (point-to-point)	640 KB to 155 MB (upload and download)	(i) Highest reliability (ii) Possible high speed (iii) Recommended for big hospitals	300–1200 euro per month

in individual cases it is expedient to transfer the patient to an comprehensive stroke unit center for specialized neuroradiology interventions [9]. According to the code “Other complex neurological treatments of acute stroke (G-DRG OPS 8-98b)” such a facility should be reachable within 30 minutes. This logistic requirement is met by 71% of the participants. Concerning early rehabilitation measures, 117 participants (98%) responded that they have the capacity to carry out early physiotherapy. Speech and language therapy is available to only 71% of the hospitals, and occupational therapy to 59%.

The most important reason for participating in a teleneuromedical network is the improvement in treatment quality (82%) and the ability to avoid unnecessary patient transport (76%). Easier and faster access to expertise (72%) and the related improvement in establishing a final diagnosis (66%) constitute further medical arguments. Furthermore, participants had to assess whether the use of teleneuromedicine increased the competitiveness of their hospital, to which 67% responded in the affirmative. Table 2 shows that mainly small hospitals with <200 beds voted for this statement while hospitals with >200 beds do not have a clear tendency.

The ability to carry out systemic (i.v.) thrombolysis within their own hospitals was considered by 59% of participants and the improved professional training of doctors within the hospital was also seen as a possible motive. The reduction of length of hospital stay (LOS) in stroke patients was not associated with a main incentive for the cooperating hospitals (see Figure 4).

Table 2: Competitive advantage in relation to the size of the hospital.

$n = 119$ hospitals	Teleneurology provides a competitive advantage	Teleneurology does *not* provide a competitive advantage
Hospitals with ≤200 beds ($n = 57$)	48 (84%)	9 (16%)
Hospitals with >200 beds ($n = 62$)	32 (52%)	30 (48%)
all hospitals	80 (67%)	39 (33%)

The most significant problem area for the hospitals seems to be the financing system of telemedicine with regard to the acquisition costs of the technical equipment. This aspect represents the main factor in the modal value of the answers (43%). In addition to this the compensation for the stroke-unit center with the specialist’s consultation service (31%) as

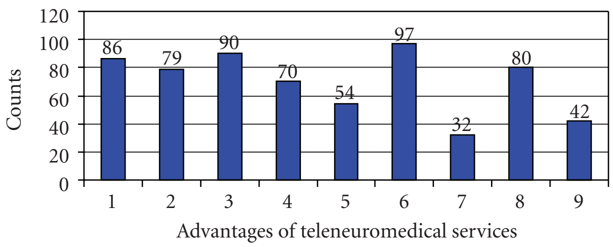

Figure 4: Advantages of teleneuromedical services: 1. easier and faster access to expertise, 2. improvement in establishing a diagnosis, 3. avoid unnecessary patient transport; 4. ability to carry out i.v. thrombolysis, 5. educational development of doctors, 6. improvement in the quality of treatment, 7. reduction of length of stay, 8. better competitiveness, 9. increasing patient numbers.

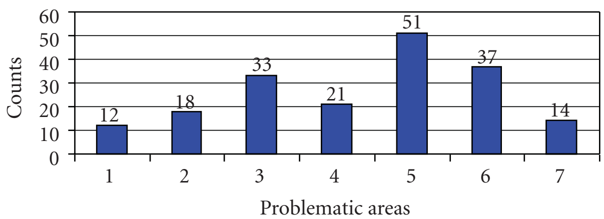

Figure 5: Problematic areas of teleneuromedical services: 1. acceptance of teleneuromedicine 2. conflict with competency boundaries, 3. legal aspects, 4. data security reasons, 5. financing problems, 6. compensation for consultation service, 7. acquisition costs for technical equipment.

well as the legal aspects of teleneuromedicine (27%) present a risk. However, data security reasons (18%), potential conflict between different specialties with competency boundaries (15%) as well as operating costs (12%) are deemed much less significant. The least problematic aspect according to the hospitals is the acceptance of teleneuromedicine among doctors (10%). 90% of the participating hospitals accept teleneuromedicine as a good supplement to the well established stroke care (see Figure 5).

4. Discussion of the Empirical Analysis

With stroke becoming increasingly even more important and neurological stroke units lacking in rural areas, teleneuromedicine emerges as a promising technique in stroke care. The present work focuses on quality improvement with the help of a teleneuromedical network system. The advantages of teleneuromedicine in acute stroke include faster and more accurate diagnoses in participating hospitals, since they have easier access to neurological expertise. To reach this goal it is, however, also necessary that such a health care configuration be accepted by participating doctors and that these doctors in turn be accurately advised. It is possible that doctors in cooperating hospitals may not always be prepared to submit to the competencies of colleagues in the treatment of "their" stroke patients. A negative attitude toward the use of teleneuromedicine might be related to this aspect. However, this was not confirmed by the present investigation. Most participants showed a ready acceptance of teleneuromedicine and ranked possible conflicts arising from competency boundaries very low.

Interestingly, improved competitiveness was cited as a predominant argument for teleneuromedicine by hospitals with less than 200 beds. This aspect can be explained by various considerations. For example, changes in the hospital system could also affect a facility's catchment area. If a neighboring hospital expands, its attractiveness increases and consequently its catchment area as well, to the detriment of other hospitals, which must adjust to a reduced load. Thus, adjustments to the range of services and capacity are necessary, the more so as with reduced patient numbers high fixed costs can no longer be covered. The result will be a decline in the attractiveness of the facility, bringing with it a further reduction of the catchment area. This process can eventually lead to the closing of a hospital. This process is already ongoing in Germany at present, and will continue into the next few years. Such adjustment mechanisms or focusing on just a few care providers may even be a political aspiration. Conversely, when a hospital, especially a small one, connects to a teleneuromedicine network, thereby improving stroke care and treatment results, its attractiveness among regional care providers will be increased. This hospital would thus have a good argument for justifying its health care mandate and for securing its existence. On the other hand, the competitive advantage can become a direct competition. Assuming each of two neighboring general hospitals, A and B, with very similar services and equipment, care for stroke patients in their respective catchment areas. Hospital A connects to a teleneuromedicine network and can then possibly attract additional stroke patients from the catchment area of hospital B, as a result of the advantages of teleneuromedicine. The precondition is that the rescue service is informed about the teleneuromedical capabilities of hospital A and delivers stroke patients primarily to this facility. Additional billable codes result for hospital A, which are tied to additional revenue [11]. However, at the same time further direct treatment costs arise from the expansion of diagnostics and treatments for the additional patients. Furthermore, one might ask if hospital A has sufficient capacity for the increased patient numbers; although if, as described, the length of in-hospital stay is reduced by the use of teleneuromedicine, it may be possible to care for more patients without increasing the hospital's capacity [7, 12]. It must be noted, however, that the reduction of length of stay was largely not confirmed by the data provided by participating hospitals in this study.

As was to be expected, financing of teleneuromedicine currently constitutes the most significant problem area. However, this aspect is not very prominent in hospitals already active in teleneuromedicine (14%). These hospitals are mainly located in Bavaria, where they are often financially supported by the state or health insurances (e.g., TEMPIS or STENO) [13]. But facilities which are in negotiations with network partners or plan to become active in teleneuromedicine might see a substantial, negotiable factor between the involved parties. Especially in those facilities for which a connection to a teleneuromedicine network is out of the question the problem of financing is quite prominent. Considering the necessary investments (hardware, software, IT support, broadband etc.), lack of sufficient financial resources can be a significant reason for the failure of teleneuromedicine in a cooperating hospital. This problem can be discussed with health insurers and the state since both can profit from the use of teleneuromedicine. As a result of quality improvement in stroke care throughout the state this sort of health care configuration in less developed regions can reduce the number of those needing long-term care and the direct and indirect costs associated with it [14]. Besides this, savings can be achieved through the elimination of unnecessary patient transport. The problem is that, these effects are not immediately evident and are only noticed by the cooperating hospitals in the long term. Which operating network costs or savings result concretely are not as easily enumerated on basic acquisition. The consequence of this lack of internalization and the associated lack of incentive could be a reason that the use of teleneuromedicine is still partly out of the question for a given facility. If a list of advantages and problems is composed, however, the advantages will prevail. It should therefore be mentioned that the opportunities provided by teleneuromedicine are ranked higher by the hospitals taking part in the survey than the risks connected with it. A generalization of this statement, however, cannot be made offhand. In the discussion of the survey results, it must be kept in mind that only a certain percentage of the total population of all acute hospitals in Germany responded and that those hospitals are particularly interested in teleneuromedicine. Hospitals for which the use of telemedicine in stroke care is out of the question tend, perhaps, not to answer.

Moreover, aspects related to the implementation of thrombolysis therapy are important. A large portion of the facilities can in principle envision performing thrombolysis with the help of a teleneuromedically connected stroke expert. Doctors in cooperating hospitals are prepared to trust their colleagues from the connected stroke unit and to rely on their evaluation. While the doctors in the cooperating hospitals bear the entire responsibility for thrombolysis treatment, for most of them the medical advantages and the associated benefits to the stroke patients are certainly in the foreground, so that when weighing the options, the arguments in favor of a thrombolysis treatment or bridging concept win out. The economic aspect of reducing unnecessary transfers, which are often very time consuming, can be largely confirmed by participating hospitals. If a stroke patient does not reach the cooperating hospital within 4.5 hours, after onset of symptoms [15], intravenous thrombolysis is no longer justified. Therefore, time should be used as effectively as possible, since up to the point of administration of the medication, appropriate examinations as well as the teleconsultation must be completed, and the success rate of thrombolysis decreases with each passing minute [16]. The brevity of this time period and especially the lengthy pre-hospital time periods are the most significant reasons for low thrombolysis rates in cooperating hospitals. Given the logical and literature-supported supposition that time-to-recanalization is crucial, rapid and safe recanalization is a primary goal. The initial teleconsultation with CT and CT angiographic findings can quickly determine whether the patient is a suitable candidate for an interventional neuroradiological procedure, although—up to now the ideal method by which a rapid and safe recanalization is achieved is not clear. In addition to limited recanalization rates, current IA therapies, particularly IA thrombolytics and mechanical devices, can take hours to achieve recanalization. In this case a so-called bridging procedure with initially intravenous thrombolysis can first be begun, and the patient can then be transferred to a specialized interventional neuroradiology while undergoing treatment without time delay [9, 17–19]. In acute basilar artery occlusion, M1 occlusion of the middle cerebral artery and occlusion of the internal carotid artery, intra-arterial thrombolysis or/and endovascular mechanical recanalization may result in higher recanalization rates than intravenous thrombolysis alone. Bridging IV/IA thrombolytic therapy for such acute stroke patients appears to be safe and yields higher recanalization and improved survival rates, as well as an overall improved chance for a better outcome. However many patients are admitted to community hospitals, where endovascular therapy is usually not readily available. In this setting a teleneuromedical supported proper selection of stroke patients is mandatory, who will benefit from an initialization of thrombolysis within a community hospital with simultaneous referral to a comprehensive stroke center, thus leading to a better functional outcome of stroke patients. However randomized controlled trials will have to confirm the expected benefit of bridging IV/IA thrombolysis with subsequent on-demand mechanical recanalization on clinical outcome [20–22].

The present investigation showed that most participants had sufficient equipment to perform thrombolysis. The recommendation of the German Stroke Society, that stroke patients undergo a CT scan within 25 minutes at most, was fulfilled with an average of 14.42 minutes of all responses. Even with a standard deviation of approx. 10 minutes it is still possible to reach this goal. It can be concluded that the internal structures and procedures within most of the participating hospitals seem to be efficient enough to guarantee quick access to a CT scan [23]. In addition, the response patterns show that the technical requirements do not stand in the way of becoming active in teleneuromedical care. The question arises whether in those hospitals which do not meet this requirement, inefficient internal organization could be the culprit. Another reason might be that these hospitals share the use of a CT with other facilities, for example, an external radiology service, and therefore delays may occur. Because of limited availability and the resulting longer “Time to MRI”, it can be deduced that in hospitals having both imaging methods at their disposal, CT will often be primarily used for initial diagnosis in the treatment of stroke patients. Both methods may be used later in the course of the treatment to strengthen the validity of the diagnostics [24, 25]. Failure to meet the 4.5 hour deadline, after which intravenous thrombolysis cannot be initiated, might also be due to an information deficit on the patient’s part. For some, the symptoms of stroke are not known, at least not sufficiently so that calling the ambulance is often too late.

For this reason there is a continuous necessity to educate the population to the importance of seeking stroke treatment as quickly as possible. It remains questionable to what extent a cooperating hospital can contribute to this, particularly as only one third of the facilities consider this a way to raise the thrombolysis rate. The cooperating hospitals consider the medical exclusion criteria much more significant for the low thrombolysis rate [4, 6, 26].

5. Examples of Exsisting Telestroke Networks in Routine Practise

Telemedicine technologies have been shown to be useful and effective in the remote neurological evaluation and treatment of acute stroke patients and is now used at several hospitals in Europe and the United States as an option for stroke patients to have access to cerebrovascular expertise. The effect of this concept was evaluated in the TEMPIS project, where five regional hospitals with a telestroke concept were matched with five regional hospitals without a telenetworking system. During two years stroke patients were monitored and the three-month outcome was studied. In an multivariate analysis the stroke treatment in the TEMPIS project showed a significantly better result compared with the nonnetworking hospitals and the thrombolysis rate was ten times higher [13].

Many physicians, especially nonneurologists, remain hesitant to use rt-PA in acute stroke patients, suggesting that additional training methods and tools are desperately needed in many communities [27]. Since the NINDS-sponsored trial of rt-PA in acute stroke was conducted at a relatively small number of experienced stroke centers, one commonly expressed concern is that similar results might not be obtained when rt-PA is used in a variety of clinical settings. After publication of the NINDS trial results more than a dozen reports of experience with rt-PA in open-label, routine clinical use have been published. In 2639 treated patients, the symptomatic intracerebral hemorrhage rate was 5.2% (95% confidence interval 4.3–6.0) slightly lower than 6.4% rate of the NINDS trial (National Institute of Neurological Disorders and Stroke) [28]. The mean total death rate (13.4%) and proportion of subjects achieving a very favorable outcome (37.1%) were comparable to the NINDS trial results [29]. As a result community hospitals will increasingly face medicolegal risks both for treating and for not treating patients with newly available agents. With a "back up" of stroke experts in a professional telenetworking system patients and family members can be assured that they speak with the expert "face to face" or "online" in the emergency unit and that all treatment options are standardized and discussed. This will release a huge burden from the less stroke experienced doctors in the local hospitals in rural areas since a major problem confronting all community hospital stroke programs is one that has been called the "frequency factor". Since a small number of stroke patients will qualify for acute interventions such as TPA thrombolysis, a stroke team could have difficulties in running effective. A study investigating the routine use of systemic TPA thrombolysis reports an increase in in-hospital mortality after administration of TPA in hospitals with <5 thrombolytic therapies within 1 year [30]. These findings underline the need to have an experienced stroke expert involved in the management of an acute stroke patient since urgent therapeutic decisions in emergency stroke care have to be made on the basis of brain imaging and a structured clinical examination. With a good knowledge of functional and vascular cerebral anatomy the stroke expert can quickly determine the neuroanatomic localization of the brain lesion and can guide special treatment options. Since such experience and resources are available mainly in stroke centers of teaching hospitals a networking system can allow each hospital to have access to the experience of all programs in the network.

In Germany telemedicine is beginning to be further established. For example, the NeuroNet constitutes an implementation of teleneuromedicine in clinical practice and represents an intraregional teleneuromedicine network of hospitals, wherein only hospitals belonging to the HELIOS hospital group take part. This project has been in operation since 2006 [9, 31] counting among its hospitals five certified stroke unit centers, who serve as "providers" of teleneuromedical expertise including neurologist, neurosurgeons and neuroradiologists. These stroke unit centers rotate their on-call services weekly whereas the cooperating hospitals make up the regional facilities or the consumers of teleneuromedical expertise [32, 33]. In NeuroNet (http://www.helios-neuronet.de) the implementation costs were covered by the hospital group and every cooperating hospital has a mobile workstation (VIMED TELEDOC 2) with a video conferencing system, and the consult is processed by a central server that can send and receive digital radiological images in DICOM format [10]. A great advantage is that the mobility of this workstation allows for its use regardless of the location of the consulting physician. Thus, patients in various parts of the hospital can be evaluated. Since every minute lost when dealing with acute stroke implies a loss of viable brain tissue, the network system strives to carry out thrombolysis on site or, with a bridging concept, to start it on site followed by transport to a comprehensive stroke unit center after the diagnosis and initiation of therapy. These networks should help to introduce these bridging concepts in a systematic way. Part of the whole concept is also supervision and quality management with standard operation procedures (SOP) to further develop the network. Adjusted to suit available regional configurations, these networks are intended to lead to a uniform optimization of care for stroke patients. Therefore training of stroke doctors, stroke nurses and therapists are continued and training equipment like the Stroke Lysis Box (IPC:A61F-17/00, patent number 200 09 172.7) and a NIHSS training DVD (http://www.physiothek.com) were indroduced. Within a systematic peer review process quality data from all hospitals are continuously evaluated and routine data with mortality rates are observed over the years to monitor the improvements in quality of stroke care.

Furthermore, the Society of Hospitals in Saxony (KGS), together with the Regional Association of Health Care Providers (LVSK) and the Saxon Ministry of Social Welfare (SMS), have after almost two years of negotiations with all involved parties agreed on a financial framework for improving telestroke care uniformely throughout Saxony, especially in rural areas, through the establishment of teleneuromedicine networks. The comprehensive stroke unit centers are the University Hospital Dresden for eastern Saxony (SOS-NET, http://www.neuro.med.tu-dresden.de/sos-net/) and for southwestern Saxony a trio of comprehensive stroke unit centers with Aue, Chemnitz and Zwickau (TNS-NET). The criteria for the participation of hospitals is clearly defined and a team from the stroke unit centers visits the potential cooperating hospital in order to check the quality criteria. It also instructs doctors, nurses and therapists particulary in operating the equipment and evaluating stroke patients with certain stroke scales. In these networks advanced and professional training is ongoing, and especially nursing staff is educated in a "Stroke Nurse Training Program" lasting six months (http://www.dsg-info.de/pdf/Pflegefortbildung_Helios_Akademie.pdf). The German Stroke Society (DSG) and the German Neurological Society (DGN) recently published standards for telestroke services that will now lead to a general certification of these networks.

But this safe and effective telestroke and "tele-thrombolysis" service with experienced stroke experts for stroke management requires a 24 hour on demand teleconsultation service that needs to be reimbursed. In TEMPiS, the expenses for this service account 300,000 € per year. Based on the calculated savings of subsequent costs by each thrombolysis between 3300 to 4200 € [34] the absolute increase of systemic thrombolysis of 75 TPA treatments within one year would result in a total saving between 250,800 and 319,200 €. Therefore the teleconsultation service results to be cost-efficient regarding only the consultations of possible thrombolyses. In Denmark the budgetary impact and cost-effectiveness of the national use of thrombolysis for stroke administered via telemedicine was estimated. The result demonstrated that thrombolysis by telestroke network was dominant to conservative management [35]. The incremental cost-effectiveness ratio was calculated to be approximately 50.000 $ when taking a short time perspective (1 year) but thrombolysis was both cheaper and more effective after 2 years and cost effectiveness improved over longer time scales. However studies conducted from a societal perspective compared with those conducted from an institutional perspective have a tendency to overestimate the total revenue. In the absence of ongoing government grant support, any telestroke sponsoring institution must devise a business model that produces a self-sustaining profitable break-even program. The health economic model computations suggest that the macroeconomics costs may balance with savings in care and rehabilitation after as little as 2 years and that potentially large long-term savings are associated with thrombolysis devilered by teleneuromedicine.

In the United States several telestroke projects are established mostly by governmental grants and published in journals (Partners Telestroke Center; STARR; STRokE DOC; REACH; RUN-Stroke; clinicaltrials.gov) [36]. Interestingly the specialist on call (SOC, http://www.specialistoncall.com) project is a privat business model that operates with 15 neurologists covering 65 hospitals in six states dealing with 3.600 teleconsultations per year. The SOC offers flat rates for hospitals where the hospital pays one time 30.000 € for the technical equipment and a monthly fee that is adjusted to the size of the hospital. The stroke neurologists are hired by SOC and monthly payed for their stroke expert teleneuromedicine service. However in Germany the teleprojects are always connected to comprehensive stroke unit centers and mostly supported by the state system. In Saxony the costs for the technical equipment of a stroke unit center and a cooperating hospital are covered by the Saxon Ministery of Social Welfare so that the implementation of the network infrastructure was possible for each hospital that could fulfill the standardized inclusion criteria for the statewide telestroke network configuration (30.000 € one time payment for each hospital). Together with the health insurance companies in Saxony it was possible to discuss a model, where each teleconsultation can be billed with 1/3 receiving the cooperating hospital and 2/3 receiving the stroke unit center. With this billing model per teleconsult all costs have to be covered including broadband costs, IT specialists, savings for new equipment, and of course payments for the stroke experts and teaching costs. The state concept allows a stable routine teleconsultation service with incentives to use the system and possibilities for growth in order to improve the quality of the telenetworking system. Since an European consensus statement has set the goal of having all persons with acute stroke admitted to specialized treatment facilities [37] establishing such a teleneuromedicine networking system in nonurban areas might be the solution to the difficult reimbursement situation of insurance companies and the problems in finding enough stroke neurologists.

6. Conclusions

In summary, broad implementation of thrombolysis in stroke is supported by the expanding telestroke networks. With the use of modern teleneuromedicine network systems quicker access to neuromedical expertise is possible. Especially the fact that comprehensive coverage by stroke units throughout Germany does not appear to be feasible at present, teleneuromedicine represents a valueable supplement to the existing system of stroke care. However, the use of teleneuromedicine alone cannot replace optimal care provided by comprehensive stroke units. Overall, the hospitals in a network must upgrade and optimize their internal structures in a holistic operational process to improve stroke care but project data show that telestroke and telethrombolysis are practicable and can contribute to the improvement of stroke care in rural hospitals that are too distant from a specialized stroke unit.

This investigation shows that there is good acceptance for teleneuromedicine among networking hospitals and that doctors see the opportunities offered by this sort of health care configuration. Technical and organizational requirements must be fulfilled in the hospitals and medical product guidelines should be followed along with a stable financing system and the possibility for deductions by the insurers so that even small hospitals can participate in this health care configuration. From a socio-economic point of view it is precisely these facilities in rural areas far away from stroke unit centers that can profit most, in terms of telestroke care. Patient benefits and resulting potentials for cost savings have to be addressed in the teleprojects and in discussion with health care structures as can be seen in Saxony.

Acknowledgments

Special thanks, to the participating hospitals, without whom no presentation or analysis would have been possible. This paper was supported by a Grant from the HELIOS Research Center (HRC Berlin) and the expert group neuromedicine to G. W. Ickenstein (HEFÖ-ID 1798).

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 628086, 18 pages
doi:10.1155/2010/628086

Research Article

Analysis of QoS Requirements for e-Health Services and Mapping to Evolved Packet System QoS Classes

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Received 30 December 2009; Revised 20 May 2010; Accepted 19 July 2010

Academic Editor: Tasos Dagiuklas

E-Health services comprise a broad range of healthcare services delivered by using information and communication technology. In order to support existing as well as emerging e-Health services over converged next generation network (NGN) architectures, there is a need for network QoS control mechanisms that meet the often stringent requirements of such services. In this paper, we evaluate the QoS support for e-Health services in the context of the Evolved Packet System (EPS), specified by the Third Generation Partnership Project (3GPP) as a multi-access all-IP NGN. We classify heterogeneous e-Health services based on context and network QoS requirements and propose a mapping to existing 3GPP QoS Class Identifiers (QCIs) that serve as a basis for the class-based QoS concept of the EPS. The proposed mapping aims to provide network operators with guidelines for meeting heterogeneous e-Health service requirements. As an example, we present the QoS requirements for a prototype e-Health service supporting tele-consultation between a patient and a doctor and illustrate the use of the proposed mapping to QCIs in standardized QoS control procedures.

1. Introduction

With recent trends and technology advancement in the development of converged broadband next generation networks (NGNs) and advanced multimedia services, the potential has increased for delivering various e-Health services to end users "anywhere, anytime". The term e-Health has been used to refer to the use of information and communication technology (ICT) in delivering healthcare services [1]. A wide variety of e-Health services exist, including health information networks, electronic health record (EHR), telemedicine services, wearable and portable systems which communicate, health portals, and many other ICT-based tools assisting disease prevention, diagnosis, treatment, health monitoring, and lifestyle management. A related term is m-Health, referring to "mobile computing, medical sensor, and communications technologies for health care" [2]. M-Health services refer to e-Health services in mobile environments, characterized by limited resource availability and changing network conditions [3].

In general, a wide variety of services may be built on top of tools and applications that provide the necessary communications and computer-aided support (e.g., multimedia conferencing/streaming enablers, image analysis and visualization tools, immersive and collaborative virtual environments, etc.), as shown in Figure 1.

Converged NGNs are being designed to deliver different types of traffic across heterogeneous end-user environments. In order to meet the requirements of e-Health service traffic delivered over networks in conjunction with other commercial traffic (e.g., voice calls, streaming multimedia, and Internet traffic), QoS mechanisms such as class-based traffic prioritization are necessary. The wide variety of e-Health services impose different Quality of Service (QoS) requirements on underlying networks. One aspect is delay tolerance, with service requirements ranging from strict real-time and delay-intolerant data transmission (e.g., tele-consultation services involving transmission of patient physiological parameters in emergency situations) to delay-tolerant services (e.g., access to a patient's EHR; home tele-monitoring). Another aspect is

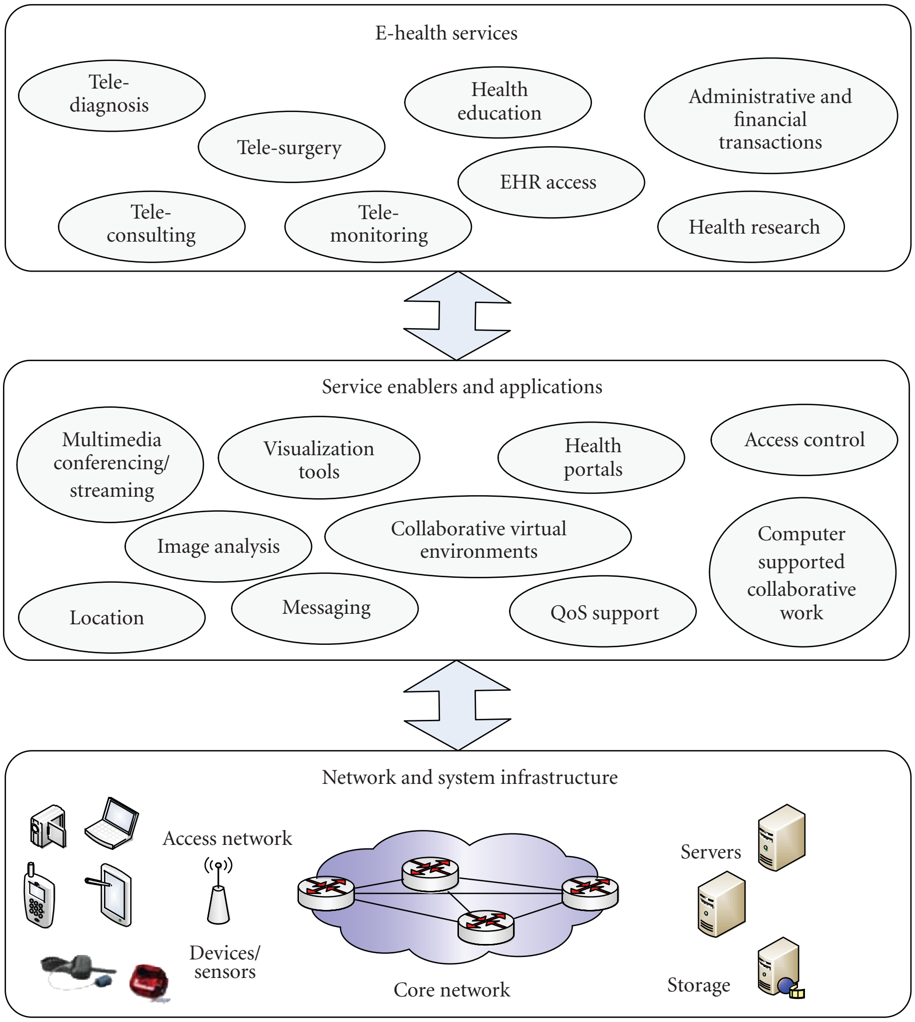

Figure 1: Layered service environment for e-Health services.

application data sensitivity to loss, with conversational voice-based applications often tolerating a certain packet loss, while data transmission (e.g., transfer of medical images) being highly loss intolerant. A significant amount of related work deals with performance requirements of e-Health services and evaluated network capabilities in meeting those requirements. In [4], the authors categorize the importance of various QoS parameters for different fields of e-Health. Prioritization and resource allocation schemes for various types of telemedicine traffic delivered over wireless networks has been addressed in [5, 6]. Further studies have more specifically focused on evaluating support for the delivery of emergency telemedicine services over high speed 3G networks [3, 7–10] and other wireless networks [11, 12], with evaluation results showing generally reliable performance. Apart from emergency scenarios, 3G networks have been evaluated in the support of various tele-consultation services involving the delivery of high-definition images [13], such as the delivery of ultrasound still and streaming images in robotic tele-ultrasonography systems [14]. Projects such as MobiHealth [15], HealthService24 [16], and MyHeart [17] have focused on developing systems for continuous tele-monitoring of patient vital signals and their transmission to healthcare institutes using 2.5/3G networks. (It should also be noted that within the European Seventh Framework Programme there are many more projects focusing on e-Health services [18], but they do not specifically consider their provisioning and QoS in 3G networks.) While this list is by no means exhaustive, it demonstrates the emerging needs which the NGN aims to answer.

Limited research, however, has focused on evaluating support for e-Health services in the context of the latest NGN standards. In order to support multimedia service delivery over a multiaccess converged all-IP core network, the Third Generation Partnership Project (3GPP) has finalized the Release 8 specifications of the Evolved Packet System (EPS), thus representing a milestone in the development of standards for the mobile broadband industry [19]. For a detailed description of EPS, an interested reader is referred to [20]. The EPS represents an evolution of the 3G UMTS characterized by higher data rates, lower latency, and a packet-optimized system aimed to deal with the rapid growth in IP traffic. A key element of the EPS is specification of a class-based QoS control concept offering service and subscriber differentiation [21]. The packet forwarding treatment received by a given session data flow is based on an assigned QoS Class Identifier (QCI) that serves as a standardized reference to node-specific treatment (e.g., scheduling weights, admission thresholds, queue management thresholds, etc.). The 3GPP specifications include nine QCIs with corresponding standardized characteristics in terms of bearer type (guaranteed versus nonguaranteed bit rate), priority, packet delay, and packet-error-loss rate.

In the context of delivering e-Health services, a key issue for the EPS QoS control architecture will be the accurate mapping of service requirements to QCIs. We emphasize that our focus in this paper is not on determining the actual network requirements of e-Health services, as a significant amount of related work deals with this issue. Rather, we aim to contribute to the ongoing research by proposing a mapping of requirements to 3GPP QCIs, based on a classification of heterogeneous e-Health service context and network QoS requirements. The proposed mapping aims to provide network operators with valuable guidelines for enabling service prioritization and making necessary network resource authorization decisions. The paper is organized as follows. In Section 2, we discuss the various requirements of e-Health services and propose a service classification. Section 3 gives a short overview of the 3GPP QoS control architecture. A mapping of e-Health service requirements to standardized QCIs is given in Section 4. Section 5 presents an example involving a tele-consultation service between a patient and a doctor used to illustrate EPS QoS control procedures and use of the proposed mapping to QCIs.

2. QoS Requirements for e-Health Services

2.1. E-Health Service Classification. Among the numerous classifications of e-Health services that may be found in literature, services are often broken down based on specific objectives into the following [13]: tele-diagnosis, tele-consultation, tele-monitoring, tele-management, tele-education, and value-added services. *Tele-diagnosis* services have been described as generally characterized by asynchronous point-to-point communication (e.g., specialists at a remote site review transmitted patient data and return a diagnosis report), while *tele-consultation* has been described as generally based on synchronous viewing and manipulation of medical multimedia data. *Tele-monitoring* in most cases refers to transmission of a patient's vital bio-signals and other related data, as in the case of home care telemedicine services [22]. Such services are often targeted at treating patients with chronic diseases or for posthospital home care, and may involve multiparametric monitoring including patient vital signs (e.g., electrocardiogram (ECG), blood pressure, saturation of peripheral oxygen (SpO2), glucose level, etc.), physical sensors (monitoring patient activity), and environmental sensors (e.g., air temperature, humidity, and air pressure). The European Commission funded MobiHealth project has focused on mobile tele-monitoring. Tele-monitoring may also involve an expert interacting with a remote examination site using audio/visual communication. For the purposes of this paper, we use the term *tele-education* as referring to any health-related education performed at a distance and in non-emergency situations. In [13], Perakis and Koutsouris use the term *tele-management* to refer to a combination of advanced tele-monitoring and tele-consultation services, such as those involving computer assisted medical interventions and automatic surgical tools (tele-surgery).

Table 1: QoS requirements for different types of e-Health services with regard to context.

Application type	Required through put	Small delay	Small jitter	Sensitivity to context
Tele-diagnosis	High	Yes	No	Yes
Tele-consultation	High	Yes	Yes	Yes
Tele-monitoring	Low	No	No	Yes
Tele-education	High	No	No	No
Access to EHR	Low/High	No	No	Yes

A classification of e-Health services based on QoS requirements has been proposed in Vouyioukas et al. [7]. The authors state that applications may generally be classified as real-time applications and near real-time applications. We note, however, that in certain cases the instances of the same generic type of service (e.g., tele-diagnosis) may have very different QoS requirements depending on actual context in which the service is invoked. For example, in an emergency situation, a remote specialist diagnosis may require near real-time transmission of medical data, while in a different, non-emergency situation, the patient medical data is transferred (with tolerance for delay) to a remote location to be analyzed by specialists. Another example of a service with strict QoS requirements and involving patient critical data transmission is tele-surgery. Hence, determining service context in terms of emergency or patient critical versus non-emergency and noncritical service delivery is crucial in providing input for traffic scheduling mechanisms. Context awareness with respect to QoS has also been addressed for m-Health services [23], where the authors use contextual information (information about the user environment) to adapt the service. Table 1 illustrates the classification proposed in [7], extended by the notion of sensitivity to context, whereby context refers to the emergency nature of the service. All application types for which use in an emergency or patient critical context may be envisioned are marked as being sensitive to context. We build upon this idea later, in the proposed mapping of QoS requirements to QCIs.

2.2. QoS Requirements for Typical e-Health Services. Typical e-Health applications may involve multimedia conferencing, transmission of patient physiological parameters, transfer of high resolution medical images, transmission of clinical/administrative data, and access to EHRs. Such applications generate traffic with very diverse network requirements, differing in required bandwidth, real-time versus non-real-time interactivity, and tolerance for packet loss. Often times, an e-Health service will involve the simultaneous transmission of multiple media flows, such as for example a mobile emergency system including audio/video, medical images, and ECG signals. In this section, we present an overview of related work that has focused on specifying the requirements of such services.

2.2.1. Multimedia Conferencing. Multimedia conferencing applications are often a key part of e-Health services, as they may be used for various communication scenarios including patient-doctor, doctor-doctor (e.g., hospital specialists and general practitioners), and patient-patient scenarios (e.g., virtual support groups). Furthermore, they may involve preorchestrated, as well as live conferencing [24]. In general, voice and video transmission applications tolerate some packet loss as a tradeoff for achieving low-delay and real-time interactivity. The Third Generation Partnership Project (3GPP) specifies the requirements for conversational audio/video applications in UMTS networks as being highly delay and jitter sensitive, with one-way end-to-end (E2E) delay bounds being 150–400 ms [25]. With regards to loss, acceptable frame erasure rates (FERs) are specified as <3% (voice) and <1% (video). Furthermore, the International Telecommunications Union (ITU) specifies objective values for IP packet transfer performance in IP networks, with bounds of 100–400 ms for E2E delay and 1×10^{-3} packet loss ratio for real-time conversational services [26]. The ITU also specifies the model for end-user QoS categories with respect to tolerance to information loss and delay tolerance, and provides indicative performance targets for audio and video applications as well as for data applications [27]. The 3GPP has specified the quality of experience and related metrics of the end-to-end multimedia service performance in 3G networks [28].

The particular requirements for multimedia conferencing used in telemedicine depend on service context. For example, a service involving audio/video conferencing between a patient and a doctor for a routine checkup may be considered “less critical” with regards to QoS guarantees (i.e., may tolerate increased degradation and delays of 150–400 ms) as compared to an audio/video conferencing service employed in an emergency accident situation where visual communication with a remote specialist doctor is imperative (i.e., “hard” real-time interactivity with one-way delay 0–150 ms).

In [7], the authors note that it is important to distinguish between the requirements for: (a) real-time video transmission, (b) offline video transmission, (c) medical video and audio for diagnostic applications, and (d) nondiagnostic video and audio. Real-time video transmission for diagnostic applications is stated as being the most demanding. Real-time diagnostic audio applications include the transmission of stethoscope audio, or the transmission of the audio stream that accompanies the diagnostic video.

2.2.2. Still and Streaming Medical Images. The transmission of high definition still images is often a part of a teleconsultation service. Examples of images include: dermatological images, X-Rays, Magnetic Resonance Images (MRIs), ultrasound images, and computed tomography (CT) [13]. With regards to bandwidth, there are no specific requirements other than the fact that low bandwidth leads to longer transmission times. An overview of image sizes and data rates corresponding to typical devices is given in Table 2 (taken from [7]). In general, an important issue in the transfer of medical data is reliable data delivery, with packet losses having potentially disastrous consequences in terms of patient diagnosis.

2.2.3. Tele-Robotic Systems. Tele-robotic systems, such as those used for tele-surgery and tele-ultrasonography, may involve the transmission of both still and streaming images. QoS requirements are generally very strict in terms of delay and loss intolerance, with invasive robotic services (tele-surgery) being patient critical and thus having more stringent requirements than noninvasive robotic services (e.g., tele-ultrasonography).

In the case of robotic tele-surgery, a key requirement is a minimal delay time from when a surgeon’s hand movement is initiated, the remote manipulator actually moves, and images are shown on the surgeon’s monitor [29]. Studies have shown that the limit of the acceptable time delay in terms of a surgeon’s perception of safety was roughly 330 ms [30]. Mechanisms for compensating delay include slowing surgeon hand movement and a remote surgeon performing tasks that require less precision, while a local surgeon performs precision-dependent tasks. Furthermore, it has been noted that two-way video conferencing among members of the healthcare team greatly enhances robotic tele-surgery [29]. With regards to reliability and error rate, relatively low data rates for transmission of robotic control data (<20 kbps) allow for error-protection coding and the possibility for transmitting equipment to send commands more than once to the receiving end [31].

The QoS requirements of a robotic tele-ultrasonography system have been conducted in the scope of the end-to-end mobile tele-echography using an ultralight robot (OTELO) project [14]. The project developed a fully portable teleoperated robot allowing a specialist sonographer to perform a real-time robotized tele-echography (ultrasonography) to remote patients. Three types of critical data are transmitted over the OTELO system: (1) robotic control data, (2) ultrasound still images, and (3) medical ultrasound streaming data, with controlled ultrasound medical streams being the most demanding in terms of data rate (in that case QCIF format and H.263 codec have been used). Focusing on a UMTS network, the authors point out that for the exchange of medical image sequences with real-time requirements,

Table 2: Data rates for typical telemedicine devices [7].

Digital device	Temporal/spatial (no. of samples/sec)	Contrast/resolution (bits per sample)	Required data rate
Digital blood pressure monitor	1	×16	<10 kbps
Digital audio stethoscope	10000	×12	approx. 120 kbps
Electrocardiogram (ECG)	1250	×12	approx. 15 kbps
Ultrasound, cardiology, radiology	512 × 512	×8	256 kB (image size)
Scanned X-ray	1024 × 1250	×12	1.8 MB (image size)
Mammogram	4096 × 4096	×12	24 MB (image size)
Compressed and full motion video	—	—	384 kbps to 1.544 Mbps

a mapping to the UMTS *Conversational* QoS class would be necessary. A test carried out on the OTELO system showed reliable functioning of the system with a minimum packet loss of less than 0.5 percent. Furthermore, performance evaluation of the ultrasound streaming images showed that round trip delays (along the expert-patient-expert path) of up to 300 ms were within acceptable boundaries of maintaining high/quality real-time interaction of the system.

2.2.4. Transmission of Patient Vital Signs. The amount and frequency of information related to monitored patient vital signs that needs to be transmitted depends on patient needs. While for some patients it may be sufficient to transmit vital signs every few minutes, other patients (e.g., those considered high-risk) may require transmission every few seconds. In [32], the authors discuss the requirements of tele-monitoring systems for cardiac patients which consist of wearable and light-weight wireless biomedical sensors (for measuring 3 lead ECG, SpO2, heartbeat, and blood pressure). Sensors communicate with a signal processing module which further transmits physiological measurements (based on patient-specific thresholds, timing and frequency as specified by a healthcare provider) via various network interfaces to, for example, hospital servers, emergency stations, local physician clinic, and so forth. Transmission requirements are mapped to the following categories based on the severity of the patient's health condition (as specified by a health provider):

(i) Class 0: highest priority requiring real-time monitoring (patients in emergency situations, or, with severe medical conditions);

(ii) Class 1: requiring near real-time monitoring within a few hours;

(iii) Class 2: requiring periodic monitoring such as twice daily;

(iv) Class 3: requiring monitoring from time to time.

The MobiHealth project [15] developed a system for the continuous monitoring of patient vital signals (using body area networks) and their transmission to healthcare institutes using GPRS and UMTS. Trials were conducted involving home care, high-risk patient monitoring, and emergency services, with the goal being to evaluate whether 2.5/3G communications technologies can support the requirements of such systems. Different trials were conducted to cover a range of bandwidth requirements (low: less than 12 kbps, medium: 12–24 kbps, and high: greater than 24 kbps), and to address both non-real-time (e.g., periodic transmission of ECG) and real-time transmission requirements (e.g., alarms, transmission of vital signs in emergency situations) [33]. At the time the trials were run (2003), the identified network barriers included restricted available data bandwidth for uplinks (in tele-monitoring systems, high data rates generally originate at user side, not server), delay variation, delays in transmission (ranging from approximately 100 ms for packet sizes of 174 bytes, to 1200 ms for packet sizes of 8122 bytes), and handover (sometimes resulting in connection loss).

2.2.5. Findings for Emergency e-Health Services. One of the most important application areas for telemedicine that relies on broadband services has been recognized as teleconsultation and tele-diagnosis in emergency accident situations, where paramedics attending to accidents do not have the necessary expertise to handle such situations [8, 13]. This results in the need for real-time transmission of accident victim's physiological parameters (e.g., ECG leads, oxygen saturation, and blood pressure) from an accident site or ambulance vehicle to a hospital/medical center. Furthermore, the transmission of still images and video streaming of the victim to specialized doctors may be of critical importance for the doctor to obtain a thorough clinical image of the patient prior to arrival at the emergency room. Hence, such services generally involve the simultaneous transmission of multiple media types.

The joint transmission of voice, real-time video, ECG signals, and medical scans from an ambulance to a hospital in a realistic cellular multiuser simulation environment based on UMTS is further considered in [8], with corresponding QoS requirements summarized in Table 3. Streaming video traffic is modeled based on measurements of H.263 encoded video. A three-lead ECG signal is sampled at 250 Hz and quantized with 12 bits per sample. While voice and video packets are considered error tolerant, ECG and file transmission require data integrity. In their simulations, the authors set a maximum allowed delay of 400 ms for voice and video traffic and a maximum delay of 300 ms for ECG traffic. The results have shown that UMTS was capable of meeting the set requirements.

Table 3: QoS requirements for medical data transfer [8].

Services	Data rate	Maximum delay	Packet loss
Audio	4–25 kbps	150–400 ms	3%
Video	32–384 kbps	150–400 ms	1%
Electrocardiogram (ECG)	1–20 kbps	approx. 1 s	Zero
File transfer (FTP)	Not available	Not available	Zero

Similar research conducted in [9] provides experimental evaluation of a mobile tele-trauma system capable of simultaneously transmitting video, medical images, and ECG signals in real 3G network conditions. Various stream parameters have been tested, including different sampling rates, frame rates, resolutions, and so forth. Images and video were compressed using JPEG and M-JPEG, respectively. The authors note that trauma specialists have suggested that a resolution of 320 × 240 (TV resolution) is enough for trauma cases, while a lower resolution of 160 × 120 may be used in extreme bandwidth conditions. With regards to requirements and stream priorities, the authors conclude the following:

(i) video requirements: loss tolerant, delay intolerant, and low priority;

(ii) image requirements: loss intolerant, delay tolerant, and medium priority;

(iii) ECG requirements: loss and error intolerant, high priority.

The same traffic priority order as used in [9] has been used by the authors in [6], who present new scheduling ideas for the integration of telemedicine traffic with other traffic types in a high capacity cellular network, focusing on handling urgent telemedicine traffic transmission with full priority, while satisfying the QoS requirements of regular traffic as well. The four types of telemedicine traffic that were considered by the authors in their simulations: ECG, X-ray files, medical images, and video. Their corresponding characteristics are as follows [6]:

(i) ECG data: sampled at 360 Hz with 11 bits/sample precision. A strict upper bound of 1 channel frame (12 ms) is set for the transmission delay of an ECG packet.

(ii) X-ray file: typical file size is 200 Kbytes. The upper bound for the transmission delay of an X-ray file is set to 1 minute.

(iii) Medical images: files sizes range between 15 and 20 Kbytes/image. The upper bound for the transmission delay of an image is set to 5 seconds.

(iv) Video: H.263 is reported as the most widely used video-encoding scheme for telemedicine video. Traces were used with mean bit rates of 91 Kbps, peak rates of 500 Kbps and standard deviation of 32.7 Kbps. Due to the need for very high-quality telemedicine video, the maximum allowed video packet dropping probability was set to 0.01%.

The performance obtained by using simulation, with telemedicine traffic set to 10% of total channel capacity, showed delay and loss values far below the upper bounds set for the particular data type.

In related work [7], the authors studied the capabilities of a High-Speed Packet Access (HSPA) 3G network in meeting the QoS requirements of emergency situations involving the joint transmission of voice, real-time video, medical data such as ECG and other vital signals, heart sound, and file transfer. Their results showed that in the case of congestion, congestion control and service prioritization may be used based on modifications in the operation of the HSDPA scheduler (critical e-Health services are treated favorably in comparison with all other kinds of calls). By prioritizing emergency e-Health services, the authors show that delay is constrained within acceptable values ranging from 150 ms to 240 ms in the downlink (for VoIP and video, resp.), and approximately 200 ms, 500 ms, and 800 ms in the uplink (for VoIP, medical data, and video, resp.).

In [3], the authors study the QoS requirements of a patient tele-monitoring system for emergency vehicles using 3G UMTS access and propose adaptive QoS decision mechanisms in light of varying network resources. They identify different types of services (audio, video, biomedical signals, transmission of high resolution images, transmission of administrative data, and remote EHR access) which can be combined in different ways based on resource availability to deliver an optimal tele-monitoring service. Combined service QoS (corresponding to simultaneous transmission of different service types in real time) is evaluated against the following thresholds (determined based on ITU standards and additional referenced work): E2E delay threshold for audio as 150 ms and video 250 ms, and packet loss rate as less than 12% audio and less than 10% video. In their previous work [34], the authors have developed an automated tool to model e-Health service requirements, and optimize application design regarding available network resources.

In [5], the author presents a resource allocation model for wireless healthcare information systems which maps e-Health applications to three different service classes based on the emergency nature and degree of interactivity (real time versus nonreal time). The classes include: (1) highest priority class incorporating life-threatening situations, characterized by very low blocking probability; (2) medium priority class representing real-time e-Health applications which are not life-critical, with the possibility of QoS degradation in order to meet the high priority class requirements; and (3) low-priority class representing non-real-time applications whose QoS requirements are met when given resources are not required by the other two classes. Simulation results serve to illustrate the benefits of assigning different priority levels to traffic based on the specific medical application requirements.

2.2.6. Access to Electronic Health Records. Existing and emerging hospital and primary health care information systems are based on the use of electronic health records (EHR). An EHR is designed to contain all possible health relevant data of a person. Over the past years, European governments have identified the EHR as the basis for nation-wide exchange and seamless integration of patient data. Access to and management of EHRs may occur in both emergency and non-emergency situations. Network delay is dependent on the amount of information that is being transmitted. However, a key requirement is reliable transmission with zero packet loss.

2.2.7. Research and Education. A wide variety of applications support health related education, such as distance learning for health professionals located in rural and remote areas [35]. Examples of applications include interactive collaborative tools and tele-conferencing, streaming audio/video, virtual classrooms, and interactive surgical simulations. Such applications are generally not considered to be as time-critical as those involving patient care, and may tolerate low delay, data loss, and unavailability. However, highly interactive surgical simulations would greatly suffer from long delays [4].

Furthermore, biomedical research may involve the transmission of high-resolution images from remote databases. In the case of remote instrument manipulation for research purposes, low-delay requirements may result from the need to position samples or adjust instrument settings [4].

2.2.8. Summary. A summary of findings related to the QoS requirements for e-Health services is given in Table 4. We group together services based on delivery requirements (real time or nonreal time) and transmission type (two-way conversational communication, unidirectional streaming, interactive request-response, and background data retrieval). For certain services, delay requirements are indicated as “not available” since no specific requirements have been found. For example, in the case of image transfer, delay will depend on image size and available bandwidth. It is clear that for emergency services, such transfer should be completed within a few seconds.

A general conclusion based on referenced work is that QoS mechanisms in NGNs are necessary in order to be able to guarantee that the requirements of e-Health services will be met, in particular for emergency and patient critical services. In the following sections, we describe the QoS control architecture specified by 3GPP and map e-Health services to standardized QoS classes.

3. QoS Control in the 3GPP EPS

In order to provide support for IP multimedia services in converged NGNs, the 3GPP has specified the EPS, comprised of both an Evolved Packet Core (formerly known as Service Architecture Evolution (SAE)), together with an evolved radio access network (E-UTRA and E-UTRAN, commonly associated with the Long Term Evolution (LTE) work item) [19]. The EPS also supports non-3GPP access, wireline (e.g., xDSL, cable), as well as fixed and mobile wireless (e.g., WLAN, WiMAX).

The EPS specifies class-based QoS provisioning, allowing operators to differentiate the treatment received by different subscribers and services. Functional network entities and interfaces responsible for providing service-aware QoS control have been specified as a part of the overall 3GPP Policy and Charging Control (PCC) architecture [36], illustrated in Figure 2, and briefly summarized next. In general, the PCC architecture extends the architecture of an IP-CAN (IP Connectivity Access Network), where the Policy and Charging Enforcement Function (PCEF) is a functional entity in the gateway node implementing the IP access to a packet data network (PDN). An Application Function (AF) located along the application-level signaling path interacts with end user applications, situated in the User Equipment (UE), and extracts session information from signaling flows. An example of an AF is the Proxy-Call Session Control Function (P-CSCF) in the IP Multimedia Subsystem (IMS). The IMS has been specified by the 3GPP (and further adopted by other standardization bodies) as a multimedia session control subsystem comprised of core network elements for the provision of multimedia services [37]. In IMS, session QoS negotiation procedures are based on an end-to-end message exchange using the Session Initiation Protocol (SIP) [38] in combination with the Session Description Protocol (SDP) [39]. An enhancement involving negotiable QoS based on advanced QoS parameter matching and optimization functionality to be included along the signaling path in the IMS has been proposed in [40].

Once the UE is switched on, a default bearer is established, based on subscribed QoS profile. Additional bearers are subsequently established and modified as needed. As shown in Figure 2, the session information is extracted by the AF (1), and is further passed to a Policy Control and Charging Rules Function (PCRF) (2), which is the policy engine of the PCC architecture. The PCRF makes session-level policy decisions to determine whether the user session can have access to requested services and, if yes, under what constraints. Decision-making is based on the session information received from the AF (2), combined with the subscription information/policies for a given user received from a Subscription Profile Repository (3), and the information about access network technology (received from the access network; not shown in the figure). The PCRF then provides session-level policy decisions to the PCEF (4) in the access gateway, where the policy decisions are enforced and used to establish a new bearer or modify an existing bearer (5). Detailed QoS signaling procedures are specified for establishing and modifying bearers [41].

In the scope of the EPS, a particular “bearer” is used to uniquely identify packet data flows belonging to a logical IP transmission path that receive a common QoS treatment between the terminal and the gateway at the edge of the access network. Hence, the bearer is the basic enabler for providing differential treatment for traffic with differing QoS requirements. According to standards, it shall be possible to apply QoS control on a per service data flow basis. The two

Table 4: Summary of QoS requirements for e-Health services.

Types of e-Health services	Example e-Health application	Commonly used media types	General QoS requirements	
			Delay	Loss
Real-time conversational tele-consultation	Audio conferencing between patient/doctor or doctor/doctor	Audio	< 150 ms E2E one-way	<1% packet loss ratio (PLR) preferred <3% limit
Real-time conversational video- based tele-consultation	Video conferencing between patient/doctor or doctor/doctor	Video	< 250 ms E2E one-way (upper bounds reported as 400 ms)	1% PLR
Real-time robotic services	Tele-surgery Tele-ultrasonography	Robotic control data, audio, video	< 300 ms round-trip-time	Zero (may tolerate minimal PLR of 0.5%)
Real-time tele-monitoring	Transmission of patient vital signs and streaming video in emergency situations	Biomedical data collected by sensors	Depends on sensors and applications < 300 ms E2E one-way for hard real-time ECG (certain applications may tolerate <1 s E2E for ECG)	Zero
Non-real-time tele-monitoring	Transmission of patient vital signs for post-hospital home care	Biomedical data collected by sensors, context data (e.g., collected by environmental sensors)	Not Available (N.A.)	Zero
Real-time tele-diagnosis	Transfer of medical images to remote location in emergency situations	Images, text, data	N.A. (Depends on image size. Smaller images should be transferred within a few seconds.)	Zero
Non-real-time tele-diagnosis	Non-emergency remote diagnosis: transfer of medical images to a remote location where specialists analyze data and return a diagnostic report.	Images, text, data	N.A.	Zero
Real-time EHR data access	Emergency medical personnel at accident/disaster site accessing a patient's EHR	Data, text, graphics, images	N.A.	Zero
Non-real time EHR data access/storage	Web-based end user (patient, doctor, additional health personnel) application for access to EHR during patient check up	Data, text. graphics, images	N.A.	Zero
Real-time messaging	Alarms sent to care givers indicating patient emergency	Text, small images, data	N.A.	Zero

Table 4: Continued.

Types of e-Health services	Example e-Health application	Commonly used media types	General QoS requirements	
			Delay	Loss
Non-real time messaging	Automated patient alerts (e.g., reminder for check up, reminder to take medication)	Text, small images, data	~10 s [26]	Zero
Conversational research and education	Collaborative research/education tools involving conversational audio/video	Audio, video	<150 ms E2E one-way for audio <250 ms E2E one-way for video (upper bounds reported as 400 ms)	<3% PLR audio <1% PLR video
Interactive research and education	Interactive surgical simulations: remote control of instruments	Data, images	<300 ms round-trip-time	1% PLR
Streaming research and education	Education tools involving streaming media	Audio, video, data	<10 s start up delay for audio and video	<1% PLR audio <2% PLR audio
Interactive health information data exchange	Health portals: Web sites offering health related data	All	~2 s/page for Web-browsing [26]	Zero
Non-interactive health information data retrieval	Distribution or diagnostic imaging textbooks	All	N.A.	Zero
Administrative and financial transactions	Patient referrals: appointment scheduling; charging and billing applications	Text	N.A.	Zero

types of bearers that have been defined are guaranteed bit-rate (GBR) and non guaranteed bit-rate (non-GBR). In the case of a GBR bearer establishment, network resources are reserved in the network (e.g., by an admission control function in a radio base station), and as long as traffic along such a bearer conforms to the reserved GBR, it is assumed that no congestion-related packet loss will occur. On the other hand, services delivered over a non-GBR bearer may experience congestion-related packet loss. Furthermore, a non-GBR bearer may be established for a longer period of time as it does not block transmission resources. A Maximum Bit Rate (MBR), defined as the upper limit for allowed bit rate on a given bearer, may be defined only for GBR bearers. An aggregate MBR (AMBR) values may also be defined for a group of non-GBR bearers (for uplink and downlink separately), thus enabling operators to limit the total amount of bit rate consumed by a single subscriber. GBR bearers are outside the scope of AMBRs. Figure 2 shows an example how different bearers correspond to different packet flows for the given IP address of the end user terminal (one bearer may be established per combination of IP address and QoS class).

Each established bearer is assigned one and only one QoS Class Identifier (QCI). A QCI is defined as a scalar value that represents *a standardized reference* to specific packet forwarding behavior to be provided to a service data flow on the path between a user equipment and access gateway. (The parameters that control the forwarding behavior are preconfigured by the operator owning the node.) The goal of standardizing QCI characteristics is to ensure that applications and services mapped to that particular QCI receive the same minimum level of QoS across multivendor networks, in multioperator environment, and in case of roaming. The 3GPP specifications include nine QCIs with corresponding standardized characteristics in terms of bearer type (also referred to as "resource type"), priority, packet delay budget, and packet-error-loss rate (given in Table 5). A primary difference between QCI 1–4 and QCI 5–9 is the bearer type (GBR versus non-GBR). The specified packet delay budget defines an upper bound for the time that a packet may be delayed between a user equipment and the access gateway, with actual packet delays—in particular for GBR traffic-expected to be typically lower as long as the end user has sufficient radio channel quality. The packet error loss rate defines an upper bound for a rate of noncongestion related packet losses.

Each QCI is further associated with a priority level (from 1 to 9, with priority level 1 being the highest). Priority levels are used to differentiate between service data flow aggregates of the same UE and also to differentiate between flow

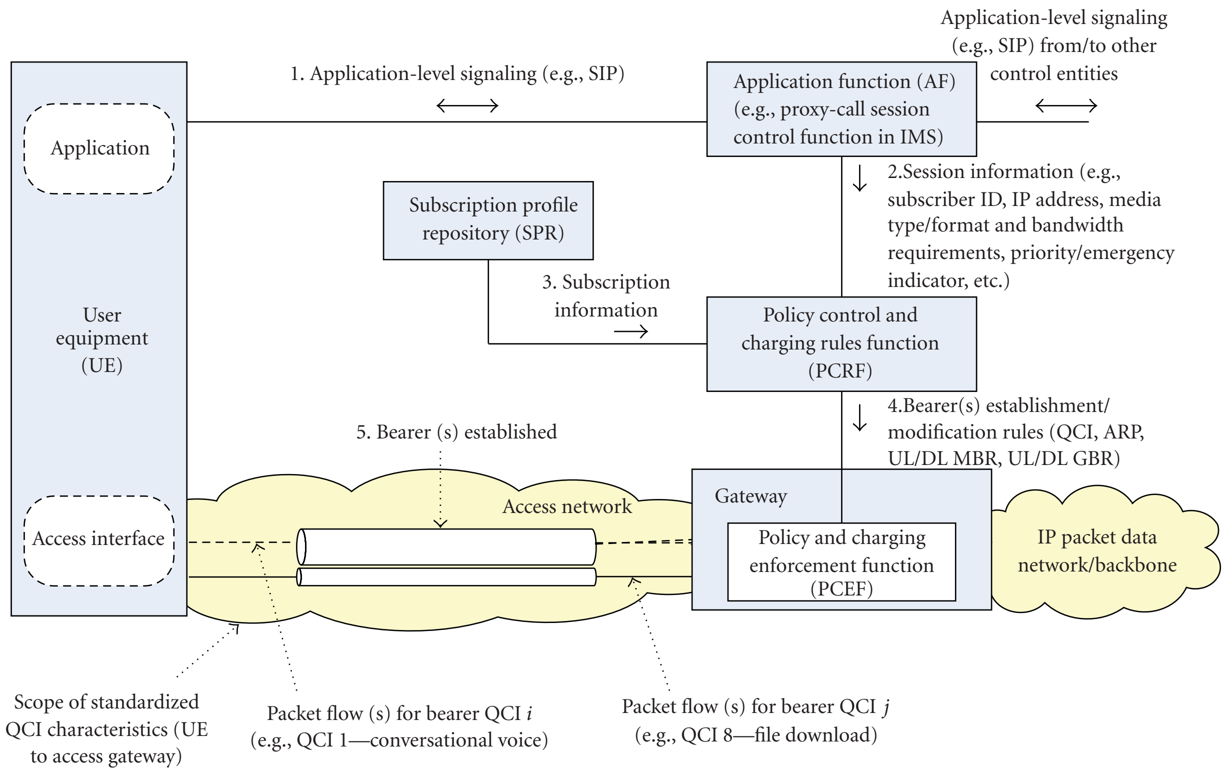

Figure 2: QoS control in 3GPP EPS policy and charging control architecture.

aggregates from different UEs (i.e., a scheduler shall meet the packet delay budget requirements of flows on priority level N in preference to meeting the packet delay budget of flows on priority level $N + 1$).

While a QCI specifies user-plane treatment for associated bearers, the QoS parameter Allocation and Retention Priority (ARP) (also signaled by the PCRF to the access gateway) specifies control plane-treatment for bearers, that is, it may be used to decide whether a bearer establishment or modification request should be accepted or rejected due to resource limitations. The ARP parameter contains information about the priority level, the pre-emption capability and the preemption vulnerability of a resource request. The priority level defines the relative importance of a bearer request. The range of the ARP priority level is 1 to 15, with 1 as the highest level of priority. Values reserved for intraoperator use (priority levels 1–8) may be used to prioritize IMS emergency calls [42]. The pre-emption capability information defines whether a service data flow can get resources that were already assigned to another service data flow with a lower priority level. The pre-emption vulnerability information defines whether a service data flow can lose the resources assigned to it in order to admit a service data flow with a higher priority level. Both values are flags which can be set to either “yes” or “no”. In situations when the system is overloaded, or, when resources must be freed up for other purposes (e.g., an incoming emergency call), bearers associated with a low ARP are released. For example, for video telephony, the operator may map video to a bearer with a lower ARP and voice to a bearer with a higher ARP, and thus have the option to drop only the video bearer if needed, while keeping the voice bearer unaffected. In normal circumstances, ARP has no impact on packet forwarding treatment for successfully established bearers.

Each EPS bearer QoS profile comprises the parameters QCI and ARP; and for GBR bearers also GBR and MBR. For aggregate (set of) EPS non-GBR bearers, AMBR values may be defined. A mapping of authorized IP QoS parameters received from the PCRF to authorized UMTS QoS parameters is performed by the translation/mapping function in the packet gateway. The rules for this mapping with regards to the QCI parameter are specified in [41] and summarized in Table 6. For the purposes of this paper, we assume that the EPS as such can provide the performance as specified and we use these values as a basis for our mapping.

4. Mapping of e-Health Service Requirements to Standardized QCIs

In the context of delivering e-Health services over an NGN architecture based on the EPS, a key issue for operators will be the accurate mapping of service requirements at session establishment/modification time to standardized QCIs. A particular service may comprise multiple media types and traffic flows that may need to be mapped to different QCIs. (An example of such a situation is shown in an illustrative example later in this paper.) Using as a basis the analysis of referenced work which has addressed the QoS requirements

Table 5: Standardized QCI characteristics [36].

QCI	Resource type	Priority	Packet delay budget	Packet error loss rate	Example services
1	GBR	2	100 ms	10^{-2}	Conversational voice
2		4	150 ms	10^{-3}	Conversational video (Live streaming)
3		3	50 ms	10^{-3}	Real time gaming
4		5	300 ms	10^{-6}	Nonconversational video (buffered streaming)
5	Non-GBR	1	100 ms	10^{-6}	IMS signaling
6		6	300 ms	10^{-6}	Video (Buffered streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		7	100 ms	10^{-3}	Voice, video (Live streaming) interactive gaming
8		8	300 ms	10^{-6}	Video (buffered streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		9			

Table 6: Rules for derivation of the authorized UMTS QoS parameters from the authorized IP QoS parameters in packet gateway [41].

QCI	Maximum authorized UMTS traffic class and traffic handling priority
1 or 2	Conversational
3 or 4	Streaming
5 or 6	Interactive, maximum authorized traffic handling priority = "1" (Signaling indication "yes" for QCI 5; signaling indication "No" for QCI 6)
7	Interactive, maximum authorized traffic handling priority = "2"
8	Interactive, maximum authorized traffic handling priority = "3"
9	Background

of heterogeneous e-Health services (summarized in Table 4), we explored the idea of mapping the previously defined types of e-Health services to QCIs. While for some types of e-Health services this mapping turned out to be rather straightforward, the question of context, as well as "relative importance" between flows belonging to different services within the same QCI, proved to be more difficult, as will be explained in more detail shortly. In order to address the requirements of e-Health in different contexts, we find it necessary to break down existing classifications as proposed in [7, 13] by considering service delivery requirements (real time or nonreal time) and transmission type (two-way conversational communication, unidirectional streaming, interactive request-response, and background data retrieval).

Furthermore, certain types of e-Health services mentioned in Table 4 are broken down into multiple e-Health classes based on service prioritization (emergency versus non-emergency). In the case of emergency situations (e.g., medical data transmission from ambulance or accident site to a hospital), data streams should be treated as parts of an emergency session, implying specific call-handling mechanisms and guaranteed QoS support [42]. Emergency service support available in current networks generally refers to emergency calls established in the circuit switched domain, such as 112 or 911 voice calls. With regards to the packet switched domain, emergency IP flows need to be identified by the P-CSCF and signaled to the PCRF (using an emergency indicator) to allow the PCRF to prioritize emergency service data flows over non-emergency service data flows within the access network. In addition to assigning a QCI value, an ARP value may be specified that is reserved for intra-operator use of emergency calls. In general (not only for emergency services) during congestion times the ARP parameter may be used to assign greater priority to bearer establishment/modification for e-Health services, as compared to other typical commercial services (e.g., non-health related calls, networked games, IPTV, etc.).

The proposed mapping is summarized in Table 7, and explained next.

We assume tele-consultation services to be based on synchronous two-way communication between involved parties based on conversational audio and/or video. Such services generally impose large bandwidth requirements and

Table 7: Proposed mapping of e-Health service types to standardized QCIs.

QCI	Priority level	Type of e-Health service	Example e-Health application
1	2	Real-time conversational voice-based tele-consultation	Audio conferencing between patient/doctor or doctor/doctor
2	2	Real-time conversational video-based tele-consultation	Video conferencing between patient/doctor or doctor/doctor
	4	Conversational research and education	Collaborative research/education tools involving conversational audio/video; virtual patient support groups involving conversational audio/video
3	1*	Invasive real-time robotic services	Tele-surgery (transfer of robotic control data in one direction, and streaming images such as ultrasound or video in the other direction)
	3	Non-invasive real-time robotic services	Portable ultrasound probe holder robotic system reproducing an expert's hand movements during an ultrasound examination
4	1*	Emergency real-time tele-monitoring	Tele-monitoring of patient vital signs (e.g., streaming ECG data) in emergency situations
	5	Non-emergency real-time tele-monitoring	Streaming of patient ultrasound images or video during routine check up
		Streaming research and education	Education tools involving streaming media
5	2	Real-time EHR data access	Emergency medical personnel at accident/disaster site accessing a patient's EHR
		Real-time tele-diagnosis	Transfer of medical images to remote location in emergency situations
	1*	Real-time messaging	Alarms sent to care givers indicating patient emergency
6	6	Non-real-time tele-diagnosis	Non-emergency remote diagnosis: transfer of medical images to a remote location where specialists analyze data and return a diagnostic report
		Non-real time EHR data access/storage	Web-based end user (patient, doctor, additional health personnel) application for access to EHR during patient checkup
		Non-real-time messaging	Automated patient alerts (e.g., reminder for check up, reminder to take medication)
7	7	Interactive research and education	Interactive surgical simulations; remote control of instruments
8	8	Non-real-time tele-monitoring	Tele-monitoring application for post-hospital home care of cardiovascular patients involving monitoring of vital signs and delivery to central hospital server
		Interactive health information data exchange	Health portals: Web sites offering health related data

Table 7: Continued.

QCI	Priority level	Type of e-Health service	Example e-Health application
9	9	Noninteractive health information data retrieval	Distribution of diagnostic imaging textbooks
		Administrative and financial transactions	Patient referrals; appointment scheduling; charging and billing applications

are delay-intolerant and loss-tolerant. We therefore map *real-time conversational voice-based tele-consultation* and *real-time conversational video-based tele-consultation* to QCIs 1 and 2 respectively, with the resource type corresponding to GBR.

As the timely and reliable delivery of e-Health services may in certain cases be considered of critical importance (i.e., a patient's well being or life is endangered), it is imperative that the top priority be assigned to corresponding traffic flows. We argue that in order to support e-Health services, particular classes need to be further broken down with regards to the assigned priority level. We therefore propose for QCI 2 to be broken down with respect to priority level into priority level 2 (for higher priority conversational video-based services) and priority level 4 (standard 3GPP priority level for QCI 2).

Since QCI 3 specifies a GBR and very strict delay bounds (50 ms), we map hard real-time interactive services to this class. We identify the requirements of *invasive real-time robotic services* (e.g., tele-surgery involving the transfer of robotic control data and streaming medical images) as corresponding to QCI 3 characteristics, but distinguish such services from *non-invasive real-time robotic services* (e.g., ultrasound examination) in terms of priority. We therefore break down QCI 3 in two classes corresponding to priority levels 1 and 3. (The priority level 1 in this context should be understood as the "first priority application data", not the "overall first priority" which is reserved for IMS signaling. In Table 7, this is denoted as priority level 1*.) A potential problem with mapping real-time interactive services to QCI 3 is that the specified packet error loss rate (PELR) for QCI 3 is 10^{-3}, which is considered too high for critical services such as tele-surgery. We have previously mentioned that error protection mechanisms may be deployed. It is interesting to note that in the case where more strict loss requirements must be met, the only mapping that "fits" in terms of both delay and loss is that to QCI 5. Considering that QCI 5 is normally used for IMS signaling (signaling indication "yes"), the operator would need to implement a special policy and resource dimensioning to secure the network resources necessary to accommodate both the signaling and emergency application traffic. (The application traffic can be distinguished from the signaling traffic by setting the Signaling Indication to "no").

Tele-monitoring services generally refer to services involving the transmission of a patient's vital biosignals and other related data. We distinguish between three types of tele-monitoring services based on delay, loss, and bit rate (GBR versus non-GBR) requirements. We map *emergency real-time tele-monitoring* services to QCI 4 and priority level 1 (1*, as noted above), assuming applications involving the streaming of patient vital signs in emergency situations and with very strict loss bounds. A delay of 300 ms may be considered acceptable. *Non-emergency real-time tele-monitoring* services are mapped to QCI 4 and priority level 5 and refer to tele-monitoring services that are not of an emergency nature, but that involve a doctor viewing the patient data in real time. Finally, *non-real-time tele-monitoring services* that are based on patient data which do not involve real-time viewing being delivered to a remote location are mapped to QCI 8 because they are delay tolerant and may be assigned a non-GBR bearer. An example of such a service is patient care, for example, for people with special needs, involving the continuous monitoring of patients at their point of need (e.g., home, work, and on the move).

We map *real-time EHR data access*, *real-time tele-diagnosis*, and *real-time messaging services* to the equivalent of QCI 5 (with same arguments regarding IMS signaling as above) due to sensitivity to loss, as well as a generally interactive (request-response pattern of the end user, rather than conversational or one-way streaming) and high-priority nature of such services. Such services do not require for bearer resources to be blocked for an extended period of time (as is the case with GBR bearers) and as such are mapped onto a non-GBR bearer type. However, due to high-priority, an operator may use the ARP parameter to specify the pre-emption capability that allows for the service data flow to be assigned resources that have previously been assigned to another service data flow with a lower priority level. While *real-time messaging services* representing emergency alarms sent to care givers are assigned a priority level of 1 (1*, as noted above), we assign a priority level of 2 to *real-time EHR data access* and *real-time tele-diagnosis* (generally characterized by data and image transfer) in order to distinguish from the priority level assigned to IMS signaling.

On the other hand, we map *non-real-time EHR data access/storage*, *non-real-time tele-diagnosis*, and *non-real-time messaging services* to QCI 6, as such services may be considered more delay tolerant, while being loss-intolerant. While tele-diagnosis services may have high bandwidth requirements due to the transfer of potentially very large medical images, messaging services generally refer to typically low-bandwidth consuming alarms or reminders.

In the case of e-Health services based on research and education, meeting QoS requirements may be considered less critical then in the case of patient care services. With

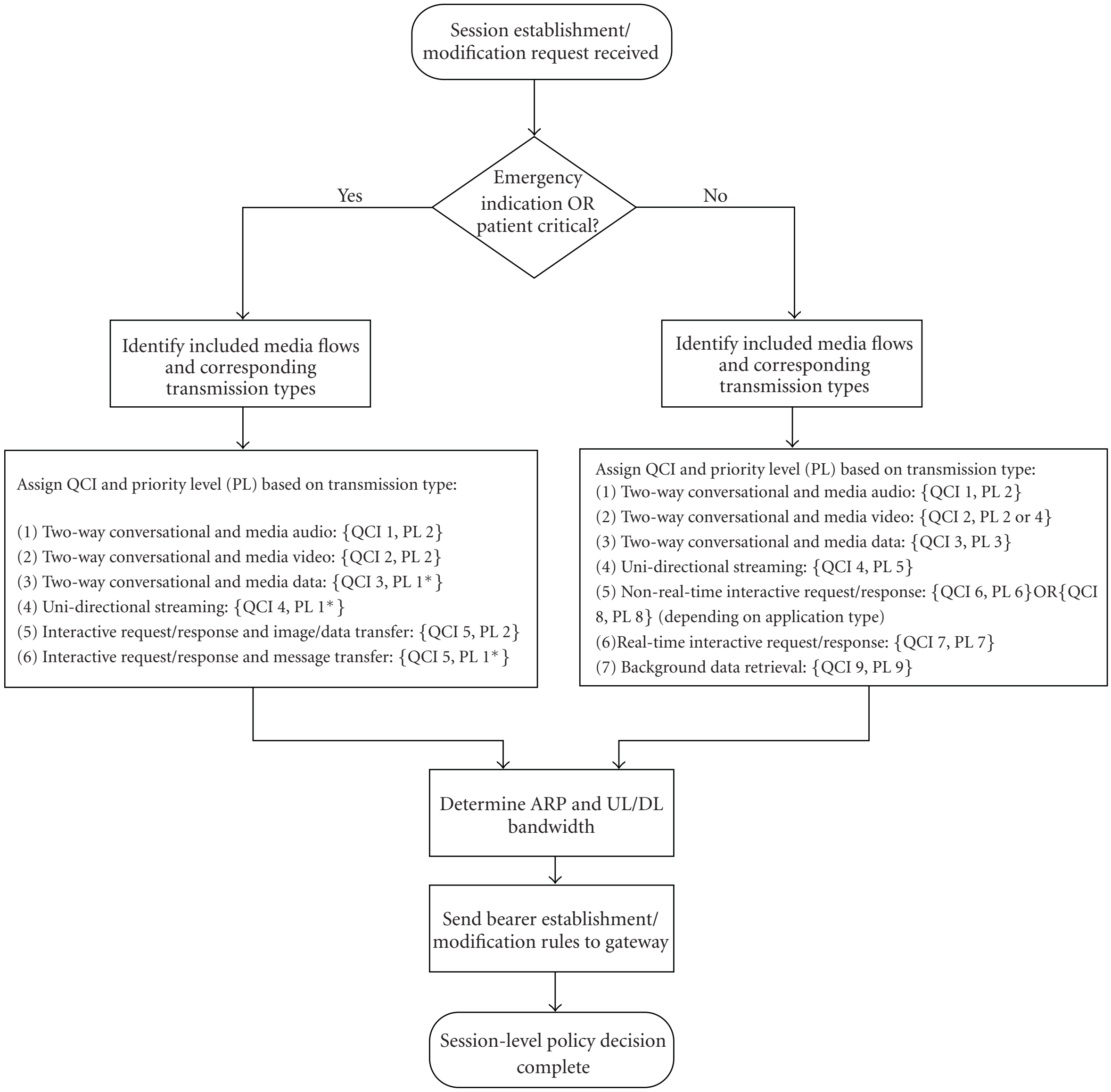

Figure 3: Scheme for assigning QCIs and priority levels to e-Health service flows.

regards to delay requirements and degree of interactivity, we distinguish between the following: *conversational research and education* services mapped to QCI 2 and priority level 4, *streaming research and education* services mapped to QCI 4 (primarily unidirectional data transfer), and *interactive research and education* services mapped to QCI 7 (characterized by a request-response pattern). In the case of services involving the retrieval of health-related information, we distinguish between *interactive health information data exchange* mapped to QCI 8 (e.g., health related web sites involving web browsing), and *non-interactive health information data exchange* mapped to QCI 9 (e.g., background download of health related data). Both QCI 8 and 9 are characterized by loss-intolerance and delay-tolerance, with QCI 8 generally referring to low-priority interactive services and QCI 9 referring to low-priority background services (i.e., are the most delay tolerant). Finally, we identify a class of e-Health services referred to as *administrative and financial transactions* that are mapped to QCI 9 and have generally low bandwidth requirements. Examples include patient referrals, appointment scheduling, charging and billing applications, and transfer of prescription orders.

A proposed scheme for assigning QCIs and priority levels to e-Health service data flows is given in Figure 3.

While standards specify performance requirements for each QCI, actual performance that will result if multiple services with a given QCI coexist in the network at the same time will depend on operator dimensioning of network resources for each class, as well as specification of ARP values including pre-emption capability and vulnerability. In that respect e-Health services do not differ from other active services in the network.

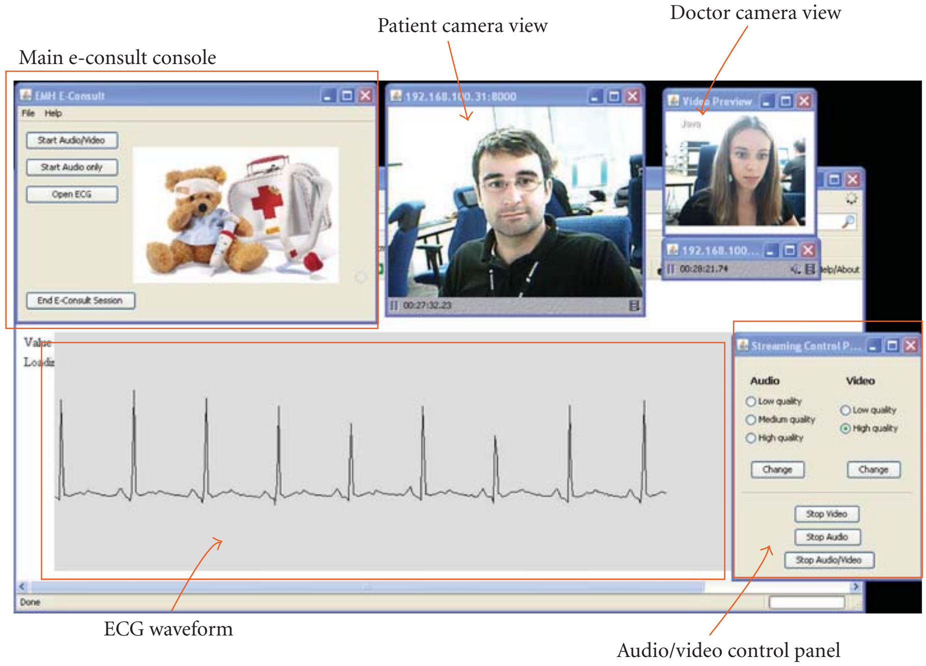

Figure 4: Early research prototype tele-consultation service—doctor desktop view.

5. Example

In order to illustrate EPS QoS control procedures and the proposed mapping of e-Health service requirements to standardized QCIs, we present a use case involving a tele-consultation service. For the purposes of this paper, the service is referred to as *E-consult* and it involves real-time video conferencing and streaming of ECG signals between a patient and a doctor. The service enables a patient or doctor to initiate an E-consult session using an early research prototype client application (Figure 4 shows the makeshift GUI). The main E-consult console offers the choice of media components to include in the session (audio/video, audio only, and ECG). In case audio/video is selected, two windows with camera views of the "patient" and the "doctor", respectively, are shown. There is also a user-friendly streaming control panel for selecting audio/video quality and starting and stopping the media flows. The ECG window shows the patient's ECG waveform.

In the prototype application, audio and video streaming corresponds to bidirectional conversational streaming, and it has been implemented using the Java Media Framework (JMF) API [43], which enables the capture, streaming, and transcoding of multiple media formats. We simulate a scenario whereby the patient has access to a remote ECG sensor unit and may choose to transmit ECG signal data to the doctor during the active session. In order to simulate streaming ECG data, we used data available from PhysioBank, a freely available archive of digital recordings of physiological signals to be used for research purposes [44]. The recorded ECG files in PhysioBank used 2-, 3-, and 12-lead ECG records sampled at 500 Hz with 16-bit resolution over a 32 mV amplitude range. For the purpose of our ECG visualization, a small sample of data extracted from ECG recording was stored in a text file in a numerical format.

The network requirements for audio/video correspond to standard requirements for audio and video streaming, with exact values for network parameters depending on the specific type of codec. A streaming control panel included in the E-consult application enables end users to configure preferences with regards to audio and video quality (different chosen quality levels will results in different codecs). Audio quality levels correspond to the following JMF codec settings: (1) low-quality—GSM, (2) medium-quality—ULAW, and (3) high quality—MPEG AUDIO. Video quality levels and JMF settings were specified as follows: (1) low-quality—H.263, and (2) high-quality—motion JPEG.

A view of the network architecture used for service delivery and a session establishment signaling diagram are given in Figure 5. In the use case involving IMS, both the doctor and the patient would access the E-consult service via their respective access networks and home IMS networks. (We selected this use case since the focus of the paper is on EPS, but in a more general case of end users connecting through their respective access networks through a common core network, QoS agreements among the providers involved in the service delivery chain should exist in order to provide end-to-end QoS.) Service establishment and modification is based on an end-to-end SIP/SDP message exchange via IMS control nodes. Service requirements in terms of media types and bandwidth requirements are specified by the end user application and signaled by using SIP/SDP.

The signaling diagram depicts the patient application as initiating the session by sending a SIP INVITE message including a session description offer specified using SDP. The doctor application replies with a 200 OK message including a

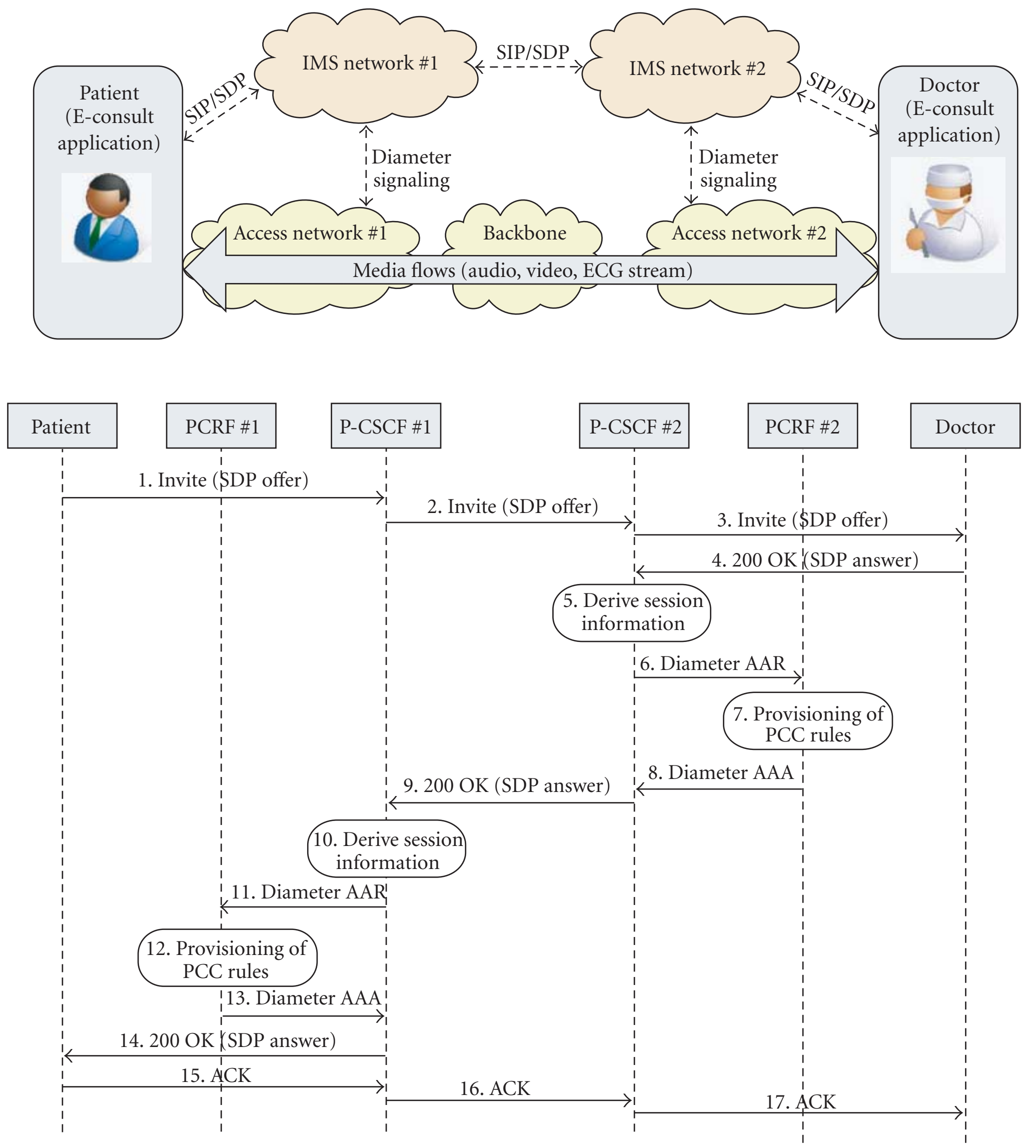

Figure 5: Simplified E-consult network view and session establishment signaling diagram.

subset of supported media types and codecs. In this case, we assume that both end users support specified audio, video, and data formats/codecs. As described in Section 3, the P-CSCF nodes are responsible for extracting session information and invoking authentication and network resource authorization procedures. The PCRF nodes are the functional entities responsible for making session-aware policy decisions and signaling bearer establishment/modification rules to the access network (referred to provisioning of PCC rules in the diagram). This interaction is performed by using an appropriate diameter [45] application protocol (as defined by the 3GPP). Step 7 illustrated in Figure 5 may be executed in parallel with steps 8 and 9, and step 10 in parallel with steps 13 and 14.

In the case of E-consult, the different media flows established as part of the session are mapped to different QCIs due to different QoS requirements. We assume the following mappings: (1) audio stream to QCI 1, (2) video stream to QCI 2, and (3) ECG signal stream to QCI 4. Considering that the example service is not of an emergency nature, there is no need to assign ARP values corresponding to emergency services. On the other hand, if this were to be treated as an emergency situation, then the ECG signal stream would be mapped to QCI 3, and operator policies would determine what ARP values to assign. Since QCI characteristics are specified for the access network (UE to access gateway/PCEF), in the case of two access networks along the end-to-end path, delay values should be summed, and a value for delay in the core network (likely to be much lower) added to it. Based on the findings described earlier, and considering that delay values specified for QCIs represent upper bounds, it may be concluded that the required end-to-end values could be met. Further research and concrete case studies would be needed to validate these conclusions in practice.

6. Conclusions and Future Work

Due to a possibly high impact on human life and well-being, e-Health services represent a category of services for which the research on QoS requirements has moved beyond the well-known properties of individual media flows. It has been shown that the context in which the service is invoked may determine the actual classification and prioritization of flows. Our work provides some general guidelines and proposes a mapping of e-Health service types to standardized QCIs in EPS as a next-generation communication technology. A use case of the E-consult service illustrates how the mapping can be applied. Future work will focus on validation of the proposed mapping for selected services.

Acknowledgment

The authors acknowledge the support of the Ministry of Science, Education, and Sports of the Republic of Croatia Research Projects no. 036-0362027-1639 and 071-0362027-2329.

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 127639, 12 pages
doi:10.1155/2010/127639

Research Article

Implementation of Compressed Sensing in Telecardiology Sensor Networks

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Received 1 November 2009; Accepted 19 July 2010

Academic Editor: Tasos Dagiuklas

Mobile solutions for patient cardiac monitoring are viewed with growing interest, and improvements on current implementations are frequently reported, with wireless, and in particular, wearable devices promising to achieve ubiquity. However, due to unavoidable power consumption limitations, the amount of data acquired, processed, and transmitted needs to be diminished, which is counterproductive, regarding the quality of the information produced. Compressed sensing implementation in wireless sensor networks (WSNs) promises to bring gains not only in power savings to the devices, but also with minor impact in signal quality. Several cardiac signals have a sparse representation in some wavelet transformations. The compressed sensing paradigm states that signals can be recovered from a few projections into another basis, incoherent with the first. This paper evaluates the compressed sensing paradigm impact in a cardiac monitoring WSN, discussing the implications in data reliability, energy management, and the improvements accomplished by in-network processing.

1. Introduction

Given the limitations imposed to cardiac patients, remote cardiac monitoring solutions, specifically wireless and wearable technologies, are of much interest and need to monitor the patient without diminishing his quality of life and are subject to constant improvements [1]. To implement a Telecardiology Sensor Network, a Personal Area Network for cardiac condition monitoring, novel yet dependable architectures may be explored using the technologies of Wireless Sensor Networks (WSNs) [2] by adding a mote to each sensor and replacing any wired connections by the motes' IEEE 802.15.4 radio capabilities. The use of motes is particularly interesting as their small size and meager power consumption is most welcomed by elder or disabled persons, the most demanding users of this type of e-health systems [1]. The most frequently monitored signals, the electrocardiogram (ECG) and photoplethysmogram (PPG), are sampled at moderate frequencies of hundreds of hertz, both for commercial and in research systems [3–9]. However, this order of magnitude is too high for the capabilities of current devices, for instance the Telos mote, so a new concept may be introduced: compressed sensing.

From the set of physiological signals generally monitored, three are here analyzed, ballistocardiogram (BCG), electrocardiogram and photoplethysmogram, all of which have been scrutinized concerning feature extraction and raw data compression, hence without aiming at compressed sensing implementation [10–12]. These signals provide important knowledge on the cardiovascular system status, and they are acquired and processed by a number of devices [1, 3–19]. For these reasons it is necessary to evaluate quantitatively the outcome of the compressed sensing application to a telecardiology system, namely, the quality of the data generated after the reconstruction of the compressed sensed signal and the benefit in the power consumption of the network.

Compressed sensing, also known as compressive sensing, has bloom in the beginning of this century, when groundbreaking results and proofs were obtained [20, 21]. The essence of this concept is that, as the signals commonly acquired and processed are not pure noise; there is some transformation in which a fairly sparse representation of the signals is obtained due to redundancies and to the presence of some sort of structure in the data. This paradigm has established that a signal sparse in a transformation may be recovered from a small number of linear measurements in a second transformation incoherent with the first [21, 22]. Consequently, the signal's compressibility is explored, instead of investigating the signal bandwidth, to reduce the number of measurements to acquire and process. These measurements are not samples but signal's representations in the second basis.

The inverse problem implicitly posed is to recover the signal from the reduced number of measurements, a possible and undetermined system, requiring a criterion to determine the optimal solution of the reconstruction. The classical approach, the use of the l_2 norm, will almost never converge to the intended solution [22], and the use of the l_0 norm is an NP-complete problem [22]. So, the solution with minimum l_1 norm is computed, formulating the so-called basis pursuit problem [23]. The l_1 approach to the problem leads to results similar to the l_0 reconstruction, and it is solvable with complexity polynomial in N. Since the user frequently requires a personal computer to interact with the e-health system, the reconstruction algorithms may be implemented at this element, which may also serve as a sink to the sensor network deployed.

In this paper, the implementation of the compressed sensing framework in wireless sensor networks for telecardiology is studied, taking as reference BCG, ECG, and PPG signals. Their compressibility and the appropriateness of compressed sensing implementation employing different basis where these signals are sparse and different interpolation methods has been studied recently [24]. The implementation of such paradigm in WSNs has a meaningful potential, since reduction on the nodes' activity is prospected, diminishing both data acquisition and data transmission loads, which will extend the lifetime of the nodes and of the Telecardiology Sensor Network (TSN) itself.

Compressed sensing algorithms were applied to simultaneous recordings of BCG, ECG, and PPG obtained from six young and healthy volunteers, with a sampling rate of 1.5 kHz to allow high-resolution analysis. After dividing the data in groups of 2048 samples, downsampled versions of each set were fed into the algorithms to be projected onto an independent and identically distributed (iid) Gaussian set of vectors, thus emulating compressed sensing. The projections were reconstructed using TwIST [25] and compared with the original high-resolution data. Besides estimating the compressibility and the quality of the reconstruction using different wavelet basis, it was also assessed the quality of the reconstructions influence of the loss of packets and the impact on the energy consumption of the devices.

2. Defining Concepts

Before detailing the results obtained and the analysis of the compressed sensing paradigm impact in a TSN, the compressed sensing methodology is formally defined and the physiological signals evaluated are described.

2.1. Compressed Sensing. The theory of this recently introduced paradigm defines that a time signal, composed by N samples, and represented by a vector x, is K-sparse or K-compressible in the basis ψ, if x can be well approximated by a linear combination of only K vectors of ψ, where K is significantly smaller than the number of samples of x. The basis ψ is referred to as the sparsity basis, and it is represented by an $N \times N$ matrix in which each column is a basis vector ψ_i. If such happens, $N - K$ expansion coefficients α_j, of the representation $x = \psi\alpha$, are zero or have a negligible value when compared to the small number, K, of dominant terms.

Compressed sensing founding results have proven that a signal x, K-sparse in ψ, may be reorganized from y, a vector composed of M linear projections of x onto another basis Φ, $y = \Phi x = \Phi\psi\alpha$. The number of projections, M, is slightly greater than K, however still much smaller than N, and Φ has to be incoherent with ψ. Incoherency indicates that the elements of Φ cannot represent sparsely the elements of ψ and vice versa. Hence, it is necessary to build Φ, the so-called measurement matrix, of dimension $M \times N$, in such a way that the signal is not damaged by the dimensionality reduction, which is respected if Φ is a random matrix with iid Gaussian entries, or if it is a Rademacher matrix with random ± 1 entries.

It is stated in the literature [21, 22] that x can be fully described by the M measurements taken, that is, the y signal. However, since $M < N$, the recovery of the original x from y is ill posed, and the recovery is only possible given the sparsity of x in ψ. Given that, the recovery of the coefficients α is feasible using optimization algorithms under an appropriate norm for the problem definition. Using the l_0 norm to search for the sparsest set of coefficients that generate y is NP-complete [22], the use of l_2 norm, despite being the natural approach, will almost never converge to the K-sparse solution [22], so the l_1 norm is applied to solve

$$\hat{\alpha} = \arg\min_{\alpha} \|\alpha\|_{l_1} \quad \text{subject to } \Phi\psi\alpha = y. \tag{1}$$

The optimization problem is specified, and the approach taken to solve it was rewriting (1) in (2) and determining the optimum α for this problem, equivalent to the basis pursuit, using TwIST [25] (Two-step Iterative Shrinkage/Thresholding), a class of algorithms extending the iterative shrinkage/thresholding algorithms, with τ being a regularization parameter. The measurement matrix Φ used was a random Gaussian matrix, and several basis ψ were employed, mostly wavelet transforms:

$$\hat{\alpha} = \arg\min_{\alpha} \|y - \Phi\psi\alpha\|_{l_2}^2 + \tau\|\alpha\|_{l_1}. \tag{2}$$

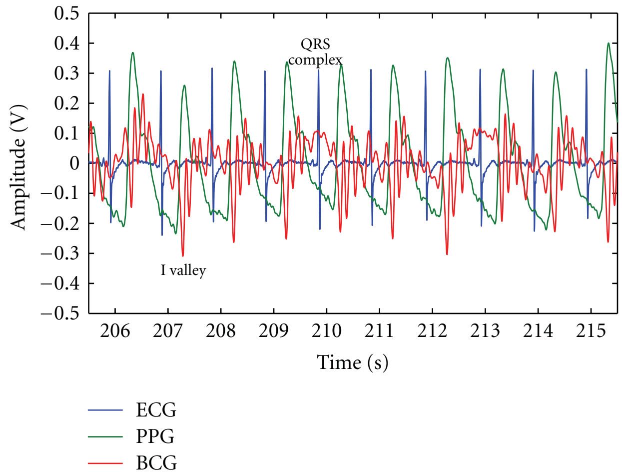


Figure 1: Evolution of the BCG (red), ECG (blue), and PPG (green) signals during 10 seconds, with QRS complex and I valley marked.

An example, with signal and transform domain results of an ECG reconstruction from 64 samples using Daubechies 4 is shown in Figure 2, specially highlighting the advances in transform domain characterization of the signal.

2.2. Cardiac Signals. Ballistocardiogram is a cardiac signal representing pressure oscillations due to the heart activity obtained recording the body's vibrations by means of a pressure sensor, lately being placed in a chair's back or seat, thus assessing both the BCG and the person's movement [19]. The BCG signal is composed by both systolic and diastolic waves, with the I valley, generated in early systole, being the most noticeable accident of the signal, as seen in Figure 1. The embedding of the sensing apparatus in a chair reduces the patient's involuntary psychophysiological responses related to the measurements' stress, consequently allowing the elimination of important bias sources of cardiologic assessment tests [26].

The electrocardiogram signal is a qualitative analysis of the electrical potentials the sinoatrial node generates during the cardiac cycle to stimulate the myocardium and may be acquired using only three chest electrodes if connected to proper amplification and filtering circuitry [19]. The QRS complex is due to ventricular depolarization and is the foremost ECG wave; Figure 1 marks it.

The photoplethysmogram represents the volume changes in an organ due to blood flow. It is a signal similar to the blood pressure waveform and it is commonly implemented also to obtain pulse oximetry, which uses a device that illumines the patient's skin and measures the light transmitted or reflected, with both infrared and visible light acceptable for use [5–7].

For the acquisition of the data used in this study, the BCG sensing device was built embedding, in the seat of a normal office chair, a piezoelectric pressure sensor, the ECG was acquired using three chest leads, and the PPG by evaluating index finger absorption of red radiation. The signals obtained are depicted in Figure 1.

An aspect which is necessary to mention is the time sparseness of the BCG and, principally, of the ECG. Both signals are characterized by a main peak, and if no projection is taken on this peak, the transformation will not be representative, as the reconstructed signal will not converge to the typical waveform, limiting the minimum number of measurements to be acquired. To the compressed sensing assessment, the data recorded at 1.5 kHz was divided in groups of 2048 samples, N, which constitute the reference waveforms. Downsampled sets, decimated at different powers of 2, from 2^2 to 2^6, were fed to the compressed sensing algorithms, resulting in a number of 512 and 32 projections, M, which represent an equivalent sampling frequency from 375 Hz down to 23.4 Hz.

3. Compression Analysis

Assessment tests of the compressed sensing of these signals were recently published [24]. Symlets 2 and 4, as well as Daubechies 2 and 4, proved to be the most appropriate wavelet transforms for implementing compressed sensing to a downsized number of cardiac signals' measurements. In spite of Biorthogonal 4.4 and 5.5 and their respective reverse, Coiflet transforms provide sparser representations for ECG, PPG, and BCG signals. The reconstruction tests conducted in a set of recordings totalizing 50 minutes showed that the application of Biorthogonal and Coiflet transformations in compressed sensing reconstruction are much worse than the Symlets and Daubechies.

Compressibility assessment, as beforehand stated, was done from a set of 2048 samples of each signal, using (3) to truncate the transformation coefficients to a percentage p (1, 5 and 20%) of their maximum, and only then computing the inverse transform

$$\alpha_i = \begin{Bmatrix} 0, |\alpha_i| \leq p \times |\alpha_{\max}| \\ \alpha_i, |\alpha_i| > p \times |\alpha_{\max}| \end{Bmatrix}. \quad (3)$$

Table 1 presents the number of nonzeroed coefficients and the normalized root mean squared deviation of the truncated inverse transform, $\mathrm{th}(x_n)$ calculated using (4). The transformations considered were Haar, Daubechies 2, Daubechies 4, Symlet 2, Symlet 4, Biorthogonal 4.4, Biorthogonal 5.5, Discrete Meyer, Coiflet 4, Reverse Biorthogonal 4.4, Reverse Biorthogonal 5.5 [27], and the Discrete Cosine Transform. Wavelet transforms were computed with

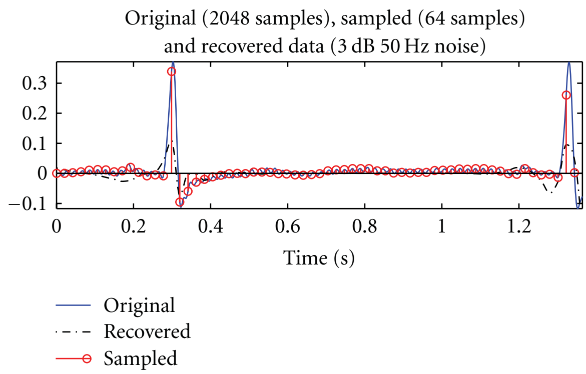
$$\mathrm{nRMSD}_{\%} = 100\sqrt{\frac{1}{n}\sum_{n=1}^{2048}\left[\frac{x_n - \mathrm{th}(x_n)}{\max(x_n) - \min(x_n)}\right]^2}. \quad (4)$$

Table 1 corroborates the heavy-tailed distribution, for numerous wavelet transforms, of the typical ballistocardiogram, electrocardiogram, and photoplethysmogram signals.

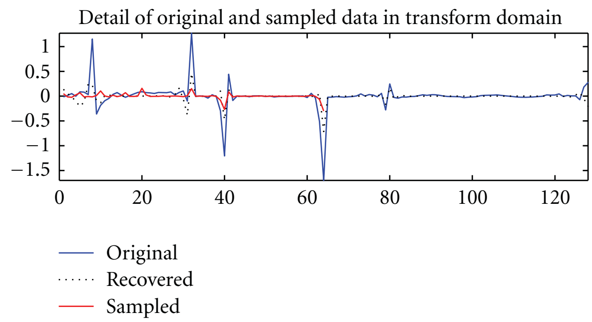
The interpretation of this table has implications in the definition of the inverse problem (2). Since the BCG and the PPG energy and sparsity basis decomposition are different from the ECG characteristic, it is understandable that the optimization problem of the latter should focus

Table 1: Truncated inverse transform nonzeros and nRMSD%.

ψ	BCG						ECG						PPG					
	# NZ			nRMSD			# NZ			nRMSD			# NZ			nRMSD		
	1%	5%	20%	1%	5%	20%	1%	5%	20%	1%	5%	20%	1%	5%	20%	1%	5%	20%
Haar	177	130	127	0.66	1.46	2.08	167	39	10	0.48	1.85	3.74	165	119	87	0.59	1.46	6.30
Db2	136	128	127	0.36	0.78	1.02	121	26	10	0.34	1.68	2.84	129	118	85	0.24	0.89	6.55
Db4	131	128	128	0.28	0.39	0.39	111	22	9	0.31	1.60	2.81	128	118	85	0.18	0.92	6.59
Sym2	136	128	127	0.36	0.78	1.02	121	26	10	0.34	1.68	2.84	129	118	85	0.24	0.89	6.55
Sym4	135	131	131	0.27	0.44	0.44	111	26	12	0.30	1.61	2.77	131	120	85	0.19	1.00	6.54
Bi4.4	134	131	131	0.27	0.36	0.36	109	26	12	0.29	1.57	2.75	131	121	85	0.19	0.96	6.64
Bi5.5	137	133	132	0.28	0.33	0.62	110	29	14	0.33	1.54	2.79	132	122	85	0.20	1.09	7.18
RBi4.4	136	131	131	0.29	0.52	0.52	113	26	12	0.32	1.64	2.90	131	120	85	0.20	1.01	6.49
Rbi5.5	137	133	132	0.30	0.42	0.57	112	26	14	0.31	1.61	2.41	131	122	84	0.20	0.81	6.41
DMey	234	212	204	0.27	0.31	0.40	165	65	47	0.32	1.53	2.43	219	186	96	0.20	1.00	6.53
Coif4	154	135	134	0.28	0.27	1.04	113	28	17	0.28	1.53	2.35	132	125	85	0.20	0.86	6.52
DCT	51	6	1	1.43	9.41	13.31	121	80	48	0.12	0.52	2.12	34	16	3	1.10	4.29	16.95



(a)



(b)

Figure 2: Original (continuous blue), sampled (continuous red), and reconstructed (dashed black) ECG signal from 64 samples. Depiction of time signal (a) and Daubechies 4 wavelet representation with level 4 of decomposition (b).

more on minimizing the solution size term (larger τ), than in the case of the others, where the emphasis should be on the error minimization, given that one knows that the solution will be less sparse. In all the implementations next presented, TwIST's regularization parameter weight was empirically defined according to (5), dependent on the data characteristics

$$\tau = \tau_{\text{coeff}} \times \max \left| \psi \Phi^T y \right|. \quad (5)$$

3.1. Lossless Medium Reconstruction. Table 1 content shows that Coiflet4, Biorthogonal 4.4 and 5.5 and their respective reverses generated sparse representations of the same order of magnitude of other transformations, but the reconstruction tests showed that its application in reconstruction for compressed sensing was much worse than the other wavelet transformations that also generated sparse representations. Daubechies 4 proved to be the one yielding best results. The signal and transform domain results of a reconstruction test are presented in Figure 2, where it is particularly noticeable the improvement in the transform domain characterization. Due to the randomness of the compressed sensing implementation, the signals may have sporadically high nRMSD, even in Daubechies 4.

Figure 3 exemplifies the dependence exhibited by the nRMSD of the reconstruction of an ECG waveform for different SNRs and number of projections, where 100% error is achieved if the TwIST algorithm does not converge to the original waveform.

3.2. Lossy Medium Reconstruction. Compressed sensing implementation in WSN is expected to attain a large benefit. In this section the quantification of this benefit will be estimated, and some issues regarding its application will be addressed. Namely, after the study of an ideal medium without packet losses, the realistic scenario of a medium where packets may be randomly lost is now approached.

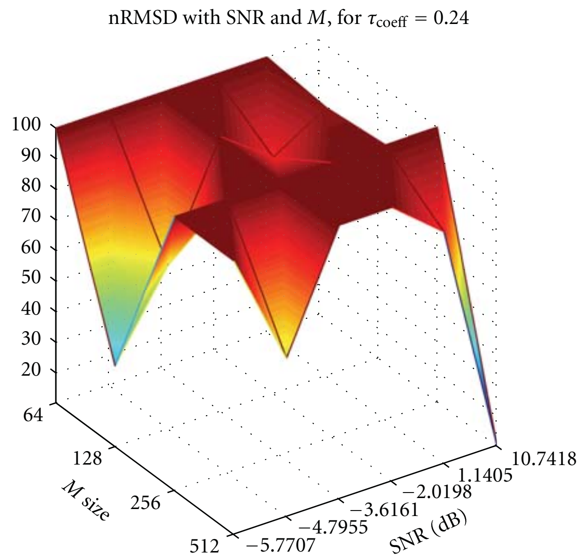


Figure 3: Depiction of SNR and M influence in the nRMSD of the ECG waveform reconstruction, for Daubechies 4 wavelet transform and $\tau_{\text{coeff}} = 0.24$.

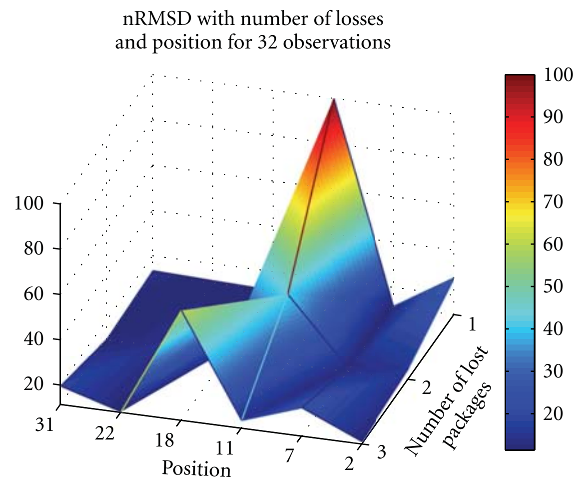


Figure 4: Dependence on number and position of lost packets, for Daubechies 4, $M = 32$, and $\tau_{\text{coeff}} = 0.24$, of the nRMSD of a reconstructed ECG waveform.

In an uncompressed sensing case, when a packet of data containing a measured value is not delivered, the signal will be distorted but the situation is not critical because the lost packet may be estimated from other received packets. When compressed sensing is used, and a data packet with one measurement is lost, it is impossible to estimate its value, due to the random multiplication, and the reconstruction error may irrupt as the algorithm may not converge at all. The worst case occurs when the minimum number of measurements are made, which is 32 in the cardiac signals case. Furthermore, as the ECG is the signal with greater time sparsity, it will be the less affected by random losses, followed by the BCG, with the PPG being the most affected.

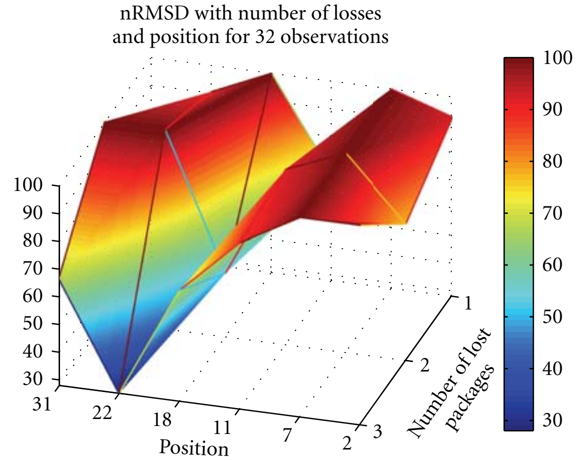


Figure 5: Dependence on number and position of lost packets, for Daubechies 4, $M = 32$, and $\tau_{\text{coeff}} = 0.14$, of the nRMSD of a reconstructed BCG waveform.

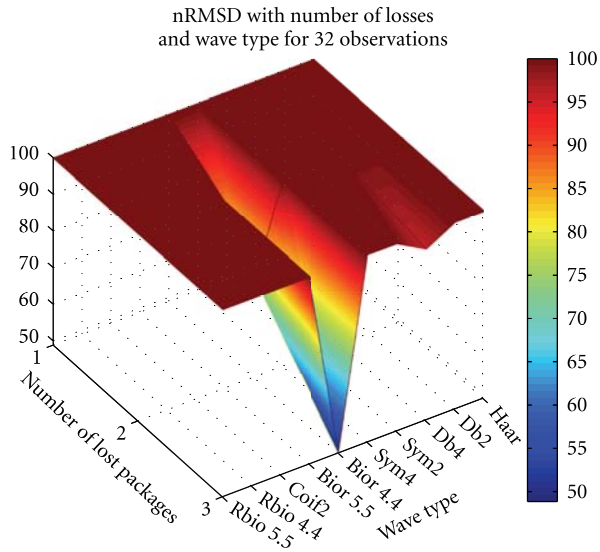


Figure 6: PPG nRMSD dependence on wavelet transform and number of packets lost, for $\tau_{\text{coeff}} = 0.14$.

Figures 4 and 5 depict nRMSD of the reconstruction when losing one to three packets, in a number of different positions, when using Daubechies 4 wavelet at level 4, for the ECG and the BCG, respectively. Figure 6 depicts the nRMSD increase in the PPG, when losing one to three packets, in random positions in the stream of 32, for different wavelet transformations.

From Figures 4 and 5 it is observable that losing a single packet may induce importance losses, with the nRMSD rising always above 20%–30%. The packet's importance is variable. If it contains information about a major wave detail (as QRS or I valley) the nRMSD can go directly to 100% or to relatively high values, as it can be seen in Figure 4 when the

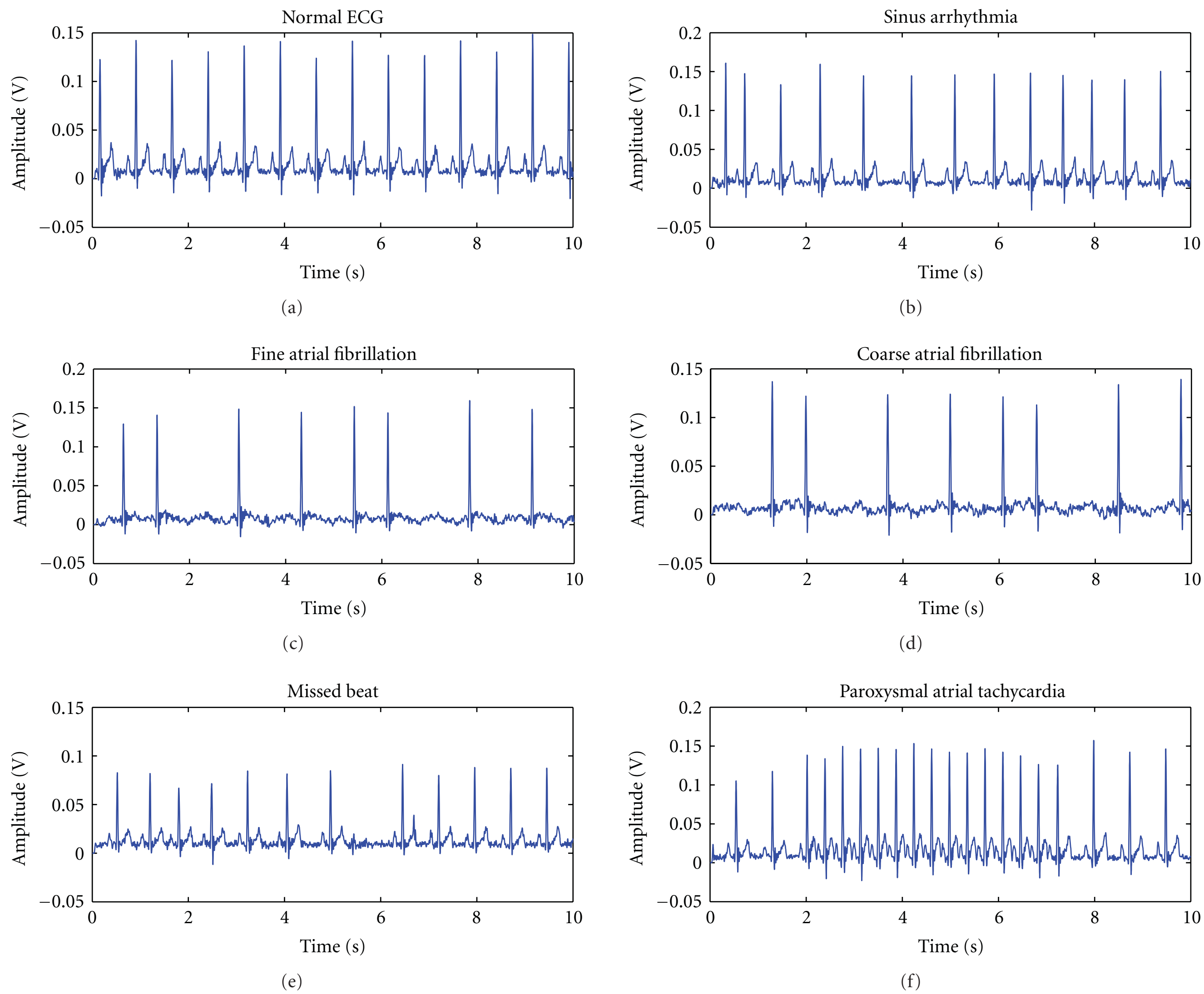


Figure 7: Signals of different cardiac arrhythmias produced by a MPS450 simulator, compared with a normal ECG.

18th packet is lost. Nevertheless, a packet lost in a moment when the signal possesses low energy will affect less the signal, as it happens when losing packets around the 22nd position in Figure 5.

From Figure 6 it is seen that only one of the transformations attains an nRMSD of 50%, which happens due to the loss of three neighboring packets. All other situations cause TwIST diverging from the PPG waveform.

3.3. Cardiac Diseases' Influence. Signals representing five common and well-known supraventricular arrhythmias were gathered, using a Fluke MPS450 patient simulator. The signals were processed using the same methodology as for real patient data. Respiration simulation was programmed, in order to mimic utterly the behavior of a sick patient. The five conditions were fine and coarse atrial fibrillation, paroxysmal atrial tachycardia, sinus arrhythmia, and missed beat. These signals were recorded for different heart rates and amplitudes and are depicted in the following Figure 7.

The signals' compressibility is immediately confirmed from the following Table 2, which presents the results for the top 5% threshold.

Regarding the results on the ECG column of Table 1, it is noticeable an increase in the number of nonzero elements, while the nRMSD is on the same order of magnitude. One significant fact is that the sparsest representations are guaranteed by the Daubechies 2 and Symlet 2 wavelets, while Discrete Meyer and Coiflets are too expensive, without improving the nRMSD. The Biorthogonal wavelets had a higher number of nonzeros, but with an important reduction of the nRMSD.

In the reconstruction tests it was again verified that Daubechies 4 proved to be generally the transformations yielding best results. Since the signals are arrhythmic ECGs, the results were expected to be analogous, which was confirmed.

Table 2: 5% Truncated inverse transform nonzeros and nRMSD% for the five arrhythmias.

ψ	Sinus		AFib fine		AFib coarse		Parox ATach		Missed Beat	
	# NZ	nRMSD	# NZ	nRMSD	# NZ	nRMSD	# NZ	nRMSD	# NZ	nRMSD
Haar	59	2.03	27	2.10	46	2.27	48	2.17	40	1.60
Db2	43	1.97	27	1.81	42	1.86	54	1.40	27	1.02
Db4	45	1.55	28	1.82	43	1.97	55	1.48	41	0.82
Sym2	43	1.97	27	1.81	42	1.86	54	1.40	27	1.02
Sym4	45	1.63	31	1.88	46	1.98	49	1.46	42	0.63
Bi4.4	46	1.43	33	1.76	42	1.70	54	1.17	36	0.48
Bi5.5	51	1.14	34	1.64	48	1.65	54	0.99	40	0.24
RBi4.4	49	1.71	33	1.72	47	1.87	57	1.14	38	0.20
Rbi5.5	46	1.76	32	1.49	48	1.60	69	0.88	45	0.47
DMey	145	1.93	148	1.86	147	2.19	287	1.68	208	0.76
Coif4	54	1.78	54	2.21	83	2.12	78	1.72	58	0.60
DCT	55	1.37	61	1.09	59	1.12	59	1.78	45	2.44

4. Discussion

4.1. Cardiac Data. Table 1 confirms the heavy-tailed distribution, for numerous wavelet transforms, of the typical ballistocardiogram, electrocardiogram, and photoplethysmogram signals. From the compression tests it was verified that Daubechies and Biorthogonal wavelets present sparse descriptions of the BCG, ECG, and PPG signals, and this can be used to reduce the sampling rate down to a minimum of 23.4 Hz, under a reasonable error. The ECG is the signal with most compressibility, followed by the BCG, because of having lower energy than the PPG.

Reconstruction experiments highlighted that TwIST's regularization parameter, τ, must be tuned specifically to the signal to be reconstructed, and that, for further optimization of the reconstruction quality, it may be necessary to adjust τ even in the same signal, when changing the subject. Regarding overhead in the computations, and in close resemblance with the data of Table 1, ECG is the signal with lower overhead, followed by the BCG, which has close results to the PPG, in the order of few seconds. It was also seen that the number of observations is a governing element on the computation time, while the depth and type of the wavelet transformation is not critical.

Although the nRMSD is not a very specific indicator of the location of the differences from the original signal, it is a good form of knowing if the major waves are well recomposed. This happens because the cardiac signals approached are known to have one or two major events, thus fail in recomposing the major waves will rise tremendously the nRMSD. Having the principal waves is vital to ensure continuous heart rate monitoring, therefore an nRMSD around 10% is likely to miss details, however it will provide a coarse approximation to the heart rate, and the major waves. If the nRMSD is about 5% the minor waves are likely to have been reconstructed, but the amplitudes and timing synchronisms are not well tuned. When the nRMSD is around 1-2%, the signal is of very good quality. Following Figure 8 illustrates these claims.

It is important to state that, to achieve high resolution in the signals, namely, in the minor waves, and in the ST segment of the ECG, it should be avoided the use of the greater compression ratios. In these cases, the minor waves are poorly defined, or absent, and the establishment of clear relations with the events responsible by T, U, and P waves is not accurate.

4.2. Data Delivery. Analyzing the previous results on a lossy scenario, it is verified the tremendous importance, for a WSN dealing with cardiac signals, to transmit all the packets of the compressed data for accomplishing a trustworthy quality of service, especially when the compression is high. This is due to the fact that the compression algorithms can deal with the reduction of the amount of data, but have no ability to hint about what has been lost. In spite of requiring the retransmission of every packet, compressed sensing implementation in a WSN will diminish the amount of data in the network, even for a modest compression rate. For instance, in a TSN with four hops from the sensor to the sink, Figure 9, with a 50% success rate in the transmissions and a protocol that attempts to transmit each packet ten times, assuming packets are saved during this period, each packet will make an average of 7.9531 transmissions to cross the WSN, or 1.9883 transmissions per hop. This result is the outcome of modeling the situation with (6), where #Att is the total number of attempts to transmit a packet, p is the success rate, k the maximum number of attempts allowed, and h the number of hops

$$\#\text{Att} = h \times \sum_{k=1}^{10} kp(1-p)^{k-1}. \tag{6}$$

Using compressed sensing in a ratio above 8 : 1, the signal will cross the WSN's four hops with less than one transmission per packet. In shorter networks and/or networks with better connectivity, the gain will be even higher. Furthermore it should be noticed that in an uncompressed sensing scenario, a 50% success rate with four hops

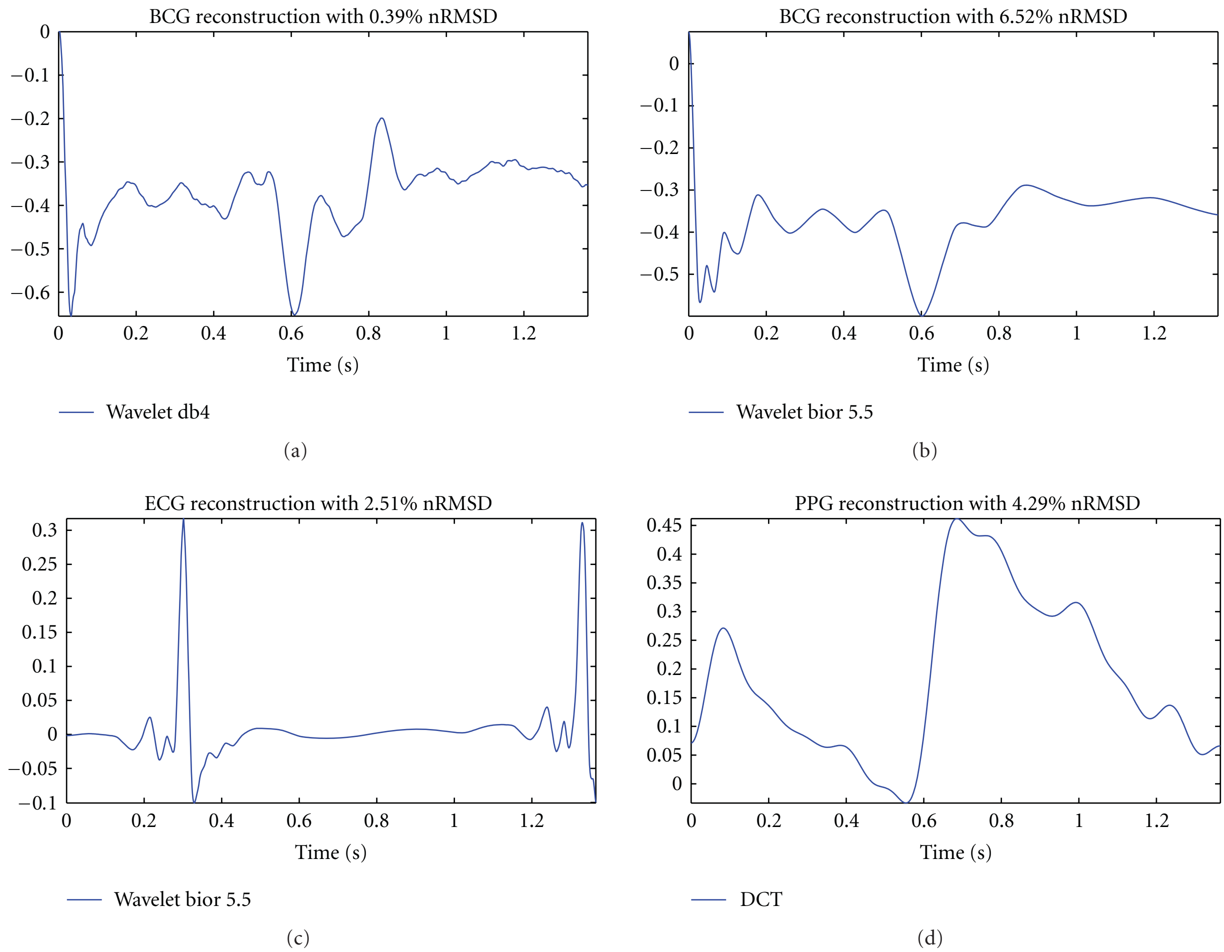


Figure 8: Example of reconstructed signals and the respective nRMSD.

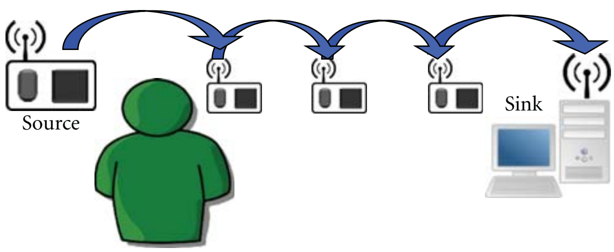


Figure 9: Example TSN, with three intermediate nodes between the source and the sink.

will force frequent retransmissions, as the probability of a packet to arrive at the sink will be of 6.25%, thus making impossible to interpolate the time signal from the few packets arrived. Thus, compressed sensing implementation, whenever possible, will be valuable. However, a reliable data transport is mandatory, recurring to negative or positive acknowledgment packets, caching mechanisms or other solution suitable for the application. Discussion on the best protocol for a number of different situations may be found in [28, 29].

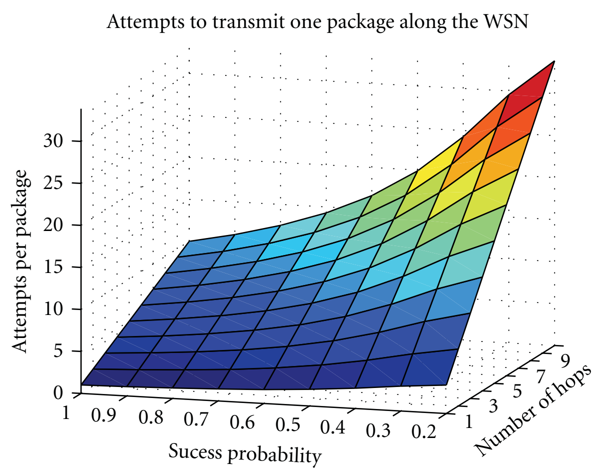


Figure 10: Number of transmissions required for a packet to cross a WSN, with variable length and success probability.

The evolution of the number of attempts to transmit a packet across the Figure 9 TSN, according to (6), for variable number of hops and transmission success rates, is depicted in Figure 10.

4.3. Energy Savings. Due to the compressed sensing implementation, the nodes' power consumption is diminished with the reduction of the sampling frequency. Further improvements, optimizing routing, topology, and node sleep periods, or joint optimization techniques [30], may also be explored to increase energy efficiency, restricted to managing the data communications without the introduction of additional delays.

Related to the reduction on the number of samples to acquire, the overhead and energy dissipated in asleep and awake tasks are reduced as well as the amount of data to send or receive via radio. These two factors are preponderant in the reduction of the power consumption, specially the radio portion, but a third factor, the reduction of the number of samples to process by the node, should also be considered. For different applications, the importance of these factors may shift. For instance, when processing tasks dominate and radio transmissions are negligible, as in [31], the number of packets to represent the waveform is reduced, thus the emitter will send fewer packets, and the receiver will be less time active. Hereby, in such situation, radio activity from both elements is reduced, while also diminishing channel occupancy.

One counter of the compressed sensing application in a TSN is the unbendable requirement of data delivery, which will oblige to an increase of radio usage due to acknowledgement messages and retransmissions. Hence, the compression rate is not proportionally reflected in energy consumption (the Telos mote requires about 20 mA to operate the radio, and 2 mA to use the microcontroller unit). To ensure energy is saved when implementing compressed sensing in a TSN, a minimum compression ratio should be estimated. The boundary for a given number of hops and success rate is obtained from (6), which defines the surface shown in Figure 9.

Energy savings were measured in the device of [5], a sensing node based on a PIC16F877A with a 16 MHz clock, 10 bit ADC, 9 bit USART connected to an RS232-Bluetooth class 1 bridge, and a MAX232 for interface voltage levels translation between the microcontroller and the serial port. Three sensing channels were implemented, acquiring ECG, BCG, and PPG. It was seen that transmitting data increases the power consumption from 0.512 W to 0.745 W.

Reducing data transmission allows savings of 1/3 of the power expenditure. The power economized per data set, P_{saved}, resulting from the implementation of compressed sensing in this sensing node is expressed in (7), where N/M is the compression ratio. The units of P_{saved} are Watt per data set

$$E_{\text{saved}} = 0.233\frac{N}{M}t. \tag{7}$$

In the concrete case of a sampling frequency of 100 Hz, to send a data set of 1.36 seconds, it would be necessary 136 packets. For an M of 32, the power saved would be of 0.990 W.

In spite of naturally allowing energy savings, the implementation of compressed sensing in a TSN must not neglect further optimizations in the network's energy management. The implementation of low power Medium Access Control (MAC) layers based on SMAC [32] for Time Division Multiple Access- (TDMA-) based approaches is important when time features of the signals are also being monitored, as pulse arrival time, an ECG-PPG relation [4–6]. If such happens, ballistocardiography nodes may be put asleep more often, among other possible considerations. To achieve low power operation without TDMA use, two well-known protocols immediately emerge to consideration, BMAC [33], which is more focused in exploiting physical layer, and XMAC [34], which exploits data link layer. Nevertheless, cross-layer MACs such as BoX-MAC [35], may bring benefits to health monitoring WSNs under compressed sensing. Already existent commercial and research solutions [1, 3–19] from the uncompressed sensing world, have idiosyncrasies which may be useful in improving energy management in a TSN.

4.4. In-Network Processing. In-network processing of the data gathered by the sensors may be an important way of improving the reconstruction results, particularly in what concerns the reconstruction of the signals' main features. From aggregation functions based on maximum value, the nodes can determine when the major waves of the signals' are present. If the WSN is capable of organizing itself, so that the sampling process concentrates on the moments where the signal is expected to have larger values, then the main waves will have enhanced resolution. The time stamp of the sampling moment must be saved to allow the posterior processing algorithms to deal with this irregularly sampled data.

In addition, recalling that the period of the cardiac signals varies between 1 and 0.4 seconds, such optimization steps require strict time synchronization in order to achieve the prospected improvements in the signal reconstruction. Due to these specificities, sensor-to-sensor Reference Broadcast Synchronization methods, as described in [36], are particularly well suited.

4.5. Network Architecture. Some aspects on how the number of hops from the sensor node to the sink affects the number of transmission attempts were aforementioned, and a depiction was presented in Figure 9, considering that the nodes have caching capabilities, until a maximum number of attempts are attained. It was also detected the importance of delivering every packet. Thus, despite the number of norms available to calculate the network lifetime [37], a TSN implementing compressed sensing collapses when a sensor fails, or when it is partitioned. These constraints are exceptionally demanding, as the sensors' data always has to be delivered. The existence of redundant nodes is profitable and necessary. In order to expand the time to fail, the intermediary nodes should have intelligent and adaptive routing algorithms, energetically efficient and with reasonable overhead. Notwithstanding the independent choice of the best protocol, joint optimization of these factors is a possibility [30].

To do personal monitoring two distinct network architectures emerge as the most likely: sensors embedded in the environment surrounding a specific house division, or opportunistic communications using the subject as a data mule, transporting data between isolated parts of the network [38]. Recent developments implemented the three sensing devices in a regular office chair [24]. If this approach is followed, the room must be populated with wireless sensors and the sink (a personal computer necessarily, to hastily reconstruct the signals and to provide a graphical user interface), and add nodes to other rooms, to enable a double or multisink setting, without transporting the chair. However, a more interesting approach for deeper and continuous cardiologic monitoring would be the embedding of ballistocardiographic sensors in the environment in objects such as chairs and wheelchairs, carpets, and beds. This deployment would allow ubiquitous monitoring of daily life activities. It would also help the telecardiology system to contextualize the measurements taken and to accompany the user's condition evolution in a broader time period. The data obtained from the monitored subject is important to carry context-aware information, so the implementation of these devices together allows pervasive monitoring with activity awareness, thus providing better care and reducing false alarms.

Implementing a WSN with numerous nodes and multiple sinks is an important field of research, as the number of acknowledgement messages increase will be unbearable [39]. The modification of the transport protocol, for instance adapting the solutions of [39–41] for reliable first packet dissemination from sink to sensor, would be profound, so probably the most practical solution would be keeping the single sink structure and establish the active WSN sink as a server, so that other devices could externally access for information on the WSN, namely, mobile phones, which are common nowadays [7–9]. When dislocating the physical apparatus to other place, the nearest sink should define itself as a server and provide access for other authorized users, following strictly or with application-required modifications the mule concept [38].

4.6. Security. The sensor data transmission is secure and does not require encryption if the values acquired are multiplied by a random floating-point matrix, thus converting the data into white noise. If a Rademacher matrix is used, encryption is necessary again, as the product by such a matrix will only change the signal of the data to transmit, so it is not enough to prevent interpretation of the data in case of intrusion. The reconstruction software has explicit knowledge of the matrix used, as well as the sensor nodes, which have it on memory, so no external access must be allowed when the measurement matrix is being defined and also to the memory sectors where it is saved.

5. Conclusions

The implementation of the compressed sensing paradigm in a wireless sensor network for cardiovascular function monitoring was assessed and found to be very profitable. The three cardiac signals studied, BCG, ECG, and PPG, were compressed and recovered with a maximum compression ratio of 64 (thus with a sampling frequency of 23.4 Hz), which is a very high profit situation in a TSN, especially regarding energy savings and network activity reduction. Nevertheless, it was also found that perfect packet delivery is mandatory. Otherwise, the reconstructed signal may be unrepresentative. Failing a packet delivery may invalidate a number of measurements from the network. Thus, in a compressed sensing implementation, to ensure in fact quality of service means to guarantee that all packets are delivered. An expression modeling the compressed-uncompressed boundary was presented, and it was found that, even in such tight delivery constrains, it is easy to achieve the zone where the benefits introduced by compressed sensing overcome the penalties, as compression ratios around 8 will be enough to reduce network traffic and augment network lifetime with high probability, in harsh scenario where only 50% of the transmissions are successful.

From the results obtained, it was seen that the approach between the two distant worlds of wireless sensor networks and compressed sensing is very interesting and may be further transposed to other areas of patient monitoring. Some difficulties to be expected in future implementations were presented in this paper and some particularities of cardiac signals were addressed. The most important were the tight demands regarding accurate waveform reconstruction and high-resolution in a time-sparse scenario, preoccupations other frequently monitored features, such as respiration or gait, have in lesser degree. Compressed sensing has thus been found as a plausible method to apply in Wireless and Telecardiology Sensor Networks.

Acknowledgments

This paper was supported by Instituto de Telecomunicações. E. Pinheiro is sponsored by Grant SFRH/BD/46772/2008 of Fundação para a Ciência e Tecnologia.

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 127519, 14 pages
doi:10.1155/2010/127519

Research Article

Flexible Macroblock Ordering for Context-Aware Ultrasound Video Transmission over Mobile WiMAX

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Received 6 December 2009; Accepted 13 May 2010

Academic Editor: Tasos Dagiuklas

The most recent network technologies are enabling a variety of new applications, thanks to the provision of increased bandwidth and better management of Quality of Service. Nevertheless, telemedical services involving multimedia data are still lagging behind, due to the concern of the end users, that is, clinicians and also patients, about the low quality provided. Indeed, emerging network technologies should be appropriately exploited by designing the transmission strategy focusing on quality provision for end users. Stemming from this principle, we propose here a context-aware transmission strategy for medical video transmission over WiMAX systems. Context, in terms of regions of interest (ROI) in a specific session, is taken into account for the identification of multiple regions of interest, and compression/transmission strategies are tailored to such context information. We present a methodology based on H.264 medical video compression and Flexible Macroblock Ordering (FMO) for ROI identification. Two different unequal error protection methodologies, providing higher protection to the most diagnostically relevant data, are presented.

1. Introduction

The most recent network technologies are enabling a variety of new applications thanks to the provision of increased bandwidth and better management of Quality of Service. Nevertheless, telemedical services involving multimedia data are still lacking behind, due to the concern of the end users, that is, clinicians and also patients, about the low quality provided. This is in particular true in the case of wireless and mobile telemedicine services. Wireless and mobile telemedicine underpins applications such as the transmission of video data from an ambulance, the rapid retrieval and remote display of video data stored in hospital databases, remote (first-level) diagnosis in rural areas, for example, robotic teleultrasonography and telesurgery.

One of the key challenges is the ability to stream medical video over wireless channels. Although wireless multimedia telemedicine services have been proposed before in [1–5], the application of these technologies in real scenarios has been constrained by the unacceptably poor quality of the medical multimedia data arising from the limited bandwidth.

For instance, cardiac ultrasound loops require a very large bandwidth. In diagnostic cardiology it would be desirable to store approximately 30 seconds of dynamic heart images per patient (i.e., three sections of the heart and 10 seconds for each section). Even if frames are digitized with 512×512 pixels with 8 bits each and the frame rate is 25 Hz, the size of the uncompressed digital video sequence would be $(512 \times 512 \times 8 \times 3 \times 10 \times 25)$ bits $=$ 196 M Bytes per examination.

Medical video compression techniques are thus required. For telemedical applications, such techniques must offer high fidelity in order to avoid the loss of vital diagnostic information. To achieve this, lossless compression techniques are often considered, but have the disadvantage of low-compression rates. Therefore, when transmission is over band-limited and error-prone channels, a compromise must be made between compression fidelity and protection and resilience to channel errors and packet loss. It has been estimated that lossy compression ratios of 1 : 5 to 1 : 29 do not result in a lowering of diagnostic accuracy [6]. Furthermore, even in situations where the final diagnosis must be carried out on an image that has been reversibly compressed, irreversible compression can still play a critical role where quick access over a bandlimited channel is required [7].

However, we can consider three types of lossless compression: information lossless compression, perceptually lossless compression, and diagnostically lossless compression. The first one is limited by the entropy (mean information) of the source; the second is such that losses are not perceived by the human eye; the latter is such that the diagnosis made on the basis of the image/video sequence is not affected by compression.

In this paper, our goal is to achieve diagnostic lossless compression and transmission of medical video. We focus on ultrasound video, although some considerations are still valid for different type of sources.

We propose to exploit all the available context information (type and goal of ongoing/stored examination, status of the patient, transmission scenario) to design an appropriate transmission system for diagnostically lossless ultrasound video transmission over WiMAX systems. For instance, coronary heart disease can be diagnosed by measuring and scoring regional motion of the heart wall in ultrasound images of the left ventricle of the heart [8]. Such information can be taken into account as context, and regions of interest (ROI) can be defined accordingly in each specific session. Multiple regions of interest can be defined, and compression/transmission strategies can be tailored to such context information. We propose a global scheme for error-resilient transmission of Ultrasound and ECG data designed based on the characteristics of the specific scenario. For this purpose we invoke a wide range of recent advancements in video compression, error resilient video coding, and transmission technologies, including specific tools of the H.264 video coding standard such as Flexible Macroblock Ordering (FMO) for ROI identification. Two different unequal error protection methodologies, providing higher protection to the most diagnostically relevant data, are proposed and the whole transmission system is specifically designed for the aforementioned scenario. The performance is evaluated over a realistic WiMAX network, by considering real measurements.

The paper is structured as follows. Section 2 provides an overview of the state of the art in wireless telemedicine systems for diagnostic video transmission and also focuses on the main advancements in the relevant enabling technologies. Following the problem statement and description of the proposed approach in Section 3, Section 4 details the system implementation and validation results. Finally, conclusions are drawn in Section 5.

2. Main Concepts and State of the Art

2.1. WiMAX. In the last few years wireless Metropolitan Area Networks increased momentum. IEEE 802.16/WiMAX (Worldwide Interoperability for Microwave Access) [9–11] is one of the most promising technologies for broadband wireless access, both for fixed and mobile use, currently being deployed in many countries worldwide.

The IEEE 802.16 standard offers broadband wireless access over long distance. Since 2001 WiMAX has evolved from 802.16 to 802.16d for fixed wireless access, and to the new IEEE 802.16e standard with mobility support [9, 10].

The latter is generally referred to as mobile WiMAX. Mobile WiMAX adds significant enhancements, including improvement of NLOS coverage by utilizing advanced antenna diversity schemes and hybrid automatic repeat request (hARQ); the adoption of dense subchannelization, thus increasing system gain and improving indoor penetration; the use of adaptive antenna system (AAS) and multiple input multiple output (MIMO) technologies to improve coverage; the introduction of a downlink subchannelization scheme, enabling better coverage and capacity tradeoff. This brings potential benefits in terms of coverage, power consumption, self-installation, frequency reuse, and bandwidth efficiency. The 802.16e standard encompasses five Quality of Service classes for different types of traffic/applications.

In particular, for medical applications in emergency areas it is important to have an easy setup of the infrastructure. At the same time, QoS is critical in medical applications, thus proper prioritization and scheduling policies should be adopted in order to enable reliable and high-quality transmission of possibly critical medical data. In [11] resource allocation is used to prioritize different type of connections (e.g., an emergency connection must have higher priority than a followup connection) over a IEEE 802.16e network. An admission control scheme is used to reserve radio resources for higher priority connections and avoid congestion. Three types of connections in the network are considered: connections from ambulances, clinics, and followup patients.

WiMAX has dramatically improved with respect to previous systems in terms of features which are critical for medical applications.

(i) High end-to-end quality;

(ii) Robustness and Reliability: the system cannot break down under stress and the connection cannot be lost;

(iii) Security: transmission of medical data should be secure and privacy of medical data must be preserved, medical data or patient identification cannot be disclosed indiscriminately; the fact that different health care providers have different access rights has to be considered.

However, the baseline WiMAX scheme lacks error protection beyond PHY/MAC and unequal error protection is not considered at PHY/MAC, hence video sequences can be largely affected by errors and packet losses. In order to improve the video quality, strong channel coding should be used at PHY layer. This would result in low-spectral efficiency. In addition, if unequal error protection is not available, the video quality will degrade significantly when a mobile subscriber station (MSS) experiences shadowing fading, temporal fading or interference. The idea of unequal error protection is to apply more robust channel coding to more important video content. Therefore, the MSS can at least decode some important video frames, for example, I frames and diagnostically important content.

For this reason we propose in this paper to adopt an unequal loss protection strategy at the application layer, to improve packet error resilience for ultrasound video sequences transmitted over a WiMAX system. The advantages of an unequal loss protection at the application layer are mainly the availability of detailed source information at this layer (no need to pass such information through the OSI protocol stack) and standard compatibility (PHY/MAC layers are standardized in WiMAX).

2.2. Wireless and Mobile Video for Telemedical Applications. Teleultrasound systems for remote diagnosis have been proposed in the last ten years [1, 2, 4, 5] given the need to allow teleconsultation when the access of the medical specialist to the sonographer is not possible.

More challenging scenarios include Ultrasound guided remote telesurgery [3] and wireless robotic teleultrasonography.

In [12], the quality of received real-time medical video sequences after transmission was just acceptable for a first diagnosis, since the available wireless technologies (2.5 G, 3 G) did not allow sufficient bandwidth for good quality video transmission. Recent studies reported by the authors in [13, 14] show the improvements achievable through the exploitation of appropriate rate-control strategies and cross-layer design over WLAN/3G systems.

Some projects and demonstrations are ongoing on multimedia telemedical application through WiMAX systems. The goal of the European IST project WEIRD [15] was the realisation of IEEE 802.16/WiMAX-based testbeds, including novel applications running on top of a WiMAX-based end-to-end architecture. The testbeds are based on real use case scenarios, including telemedicine and telehospitalization. Broadband access for medical personnel requiring high-resolution medical information in nomadic emergency camps and high-resolution video and data streaming from medical instruments were considered. The project highlighted the main challenges that WiMax still has to face in e-health applications. The goal of the “Mobile Healthcare Services” project in Taiwan [16] is to support emergency medical assistance and patient care services wherever it is required outside of a medical facility. With the assistance of high-bandwidth wireless communications (WiMAX), healthcare personnel in the field will be able to connect to critical medical resources, exchange important files, and arrange treatment, saving crucial minutes in the early treatment of patients. In Australia, with the help of Intel Australia and Airspan Networks, the organizers of the Australian Grand Prix deployed a WiMAX network to improve communication flow between the on-site trauma unit and medical specialists at the Alfred Hospital three kilometers away. Auto racing events require a medical team capable of attending to the steady stream of injuries incurred by the drivers, mechanics, and other personnel throughout the competition. The trackside trauma facility was provided with high-speed wireless connection, linking the on-site medical staff with their counterparts in a hospital three kilometers away. The WiMAX network eliminated the need for the 20-minute trips previously required to manually transport radiology images, test results, and other medical information. Furthermore, wireless web cameras installed at the remote site allowed medical staff in the field to run real-time video consultations and patient reviews with their colleagues in the hospital. The project focused on medical images and ambient video, not on medical video sequences. Further information on similar projects is provided in [17, 18].

The goal of most of the aforementioned projects is/was to demonstrate the transmission of medical data over a standard network, with no effort to tailor the characteristics of the transmission system to the specificity of the transmitted data.

One of the first works addressing the need of taking the specific characteristics of the medical application into account in the design of the transmission system was [19], presenting the design of a mobile teletrauma system using 3G Networks.

The importance of considering a specific cross-layer strategy designed with the goal of maximizing the diagnostic quality of the received information was first identified in [20] and then also addressed in [13, 14, 21, 22]. A recent work in this direction is also [23], where adaptive transmission of medical images and video is addressed using scalable coding and context-aware wireless medical networks. The authors propose a wavelet-based scalable coding scheme and context information is addressed here as the information on the patient state (normal/urgent). This work focused on teledermatology, MRI, and ambient video (no ultrasound).

2.3. Region-of-Interest Coding. Since most networks deal with a limited amount of bandwidth, scaling techniques are introduced to send less data over the network with as little inconvenience as possible for the user. One of these techniques is region-of-interest coding (region of interest (ROI)). ROI divides an image into multiple parts, the most important part typically being the one the user is observing, called the ROI.

ROI coding can be used to encode objects of interest with a higher quality, whereas the remainder of the image can be regarded as background information and can be encoded more coarsely. The advantage of this method is that the image parts that the viewer is looking at can be transmitted with a higher quality. The result is that the overall viewing experience remains satisfactory, while the transmission can be performed at lower bitrates.

Another advantage of ROI-coding is that ROIs can be transmitted first. This can be realized by the use of slices (e.g., if slice-group-0 is transmitted first, by placing the ROI in slice-group-0, it should arrive first at decoder side). When network congestion occurs, the probability of having a frame that contains at least something the viewer most likely wants to see, is higher with ROI coded imagery than without ROI.

The ROI can be defined by the user (e.g., clinician) by means of a mouse click, by making use of an eye tracking device or can be predicted, based on content recognition algorithms.

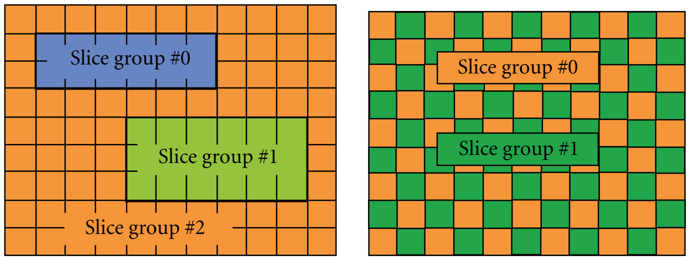


Figure 1: Examples of FMO patterns.

Medical video sequences typically consist of an area which is critical for the diagnosis and a surrounding area which provides the context, but is not critical for the purpose of the diagnosis. ROI coding appears thus as a natural methodology for medical video and ROI definition can be performed according to contextual information, either automatically or by the clinician.

Different image and video coding standards enable ROI definition, under different names. The image compression standard JPEG2000 [24] allows both the definition of a ROI of regular shape and defined by the user through a mask. The MPEG4 standard [25] proposed for the first time the concept of “objects” independently manipulated in a video sequence.

In the more recent H.264 standard [26, 27] there are several different models to implement ROI-coding, all making use of slice groups.

Indeed, the concept of ROI is not often exploited in the design of compression and transmission strategies. Reference [28] presents an implementation of multiple region-of-interest models in H.264/AVC. Compression only is addressed here. Reference [29] presents a cost-distortion optimized unequal error protection for object-based video communications, with the goal of optimizing the global distortion of each image by adapting the transmission power to provide a different protection to shape and texture information. This approach is probably the most similar to our one, although the authors focused on power adaptation (physical layer), while we propose unequal loss protection at the application layer. Furthermore, the authors did not consider medical video and did not exploit relevant context information. They exploited the “object” tool in the MPEG-4 standard, while we rely on the FMO tool in the H.264 standard for the identification of regions of interest. Reference [30] presents a region-based rate control and bit allocation for wireless video transmission. Reference [31] exploits the concept of ROI and contextual information for context-aware multi-lead ECG compression based on image codecs.

The following section describes a useful way to implement ROIs in the H.264 video coding standard.

2.4. Flexible Macroblock Ordering (FMO). The H.264 standard [26, 32] includes three profiles (baseline, main, and extended), each having a different set of functionalities. The baseline profile was designed primarily for low-cost applications with reduced computational power. This profile is mainly used in mobile applications. The most relevant functionalities in the baseline profile are FMO and Arbitrary Slice Ordering (ASO). Both techniques are used for manipulating the decoding order of the macroblocks in the picture.

A video frame consists of macroblocks which can be grouped into slices. A slice contains at least one macroblock and it can include all the macroblocks in the video frame. Using FMO, groups of macroblocks consisting of one or more slices, known as slice groups, are formed according to a specific strategy. FMO was mainly developed with the goal of improving error concealment. The FMO mode, in conjunction with advanced error concealment methods applied at the decoder, maintains the visual impact of the losses at a low level even at loss rates up to 10%. Apart from predefined patterns, fully flexible macroblock ordering (explicit mode) is also allowed, where the macroblock classification can be changed dynamically throughout the entire video sequence based on the video content. Examples of slice groups obtained through the FMO tool are reported in Figure 1.

The idea behind FMO is that if a slice gets corrupted, and the macroblocks within this slice are dispersed across the frame, it will be easier to conceal the lost macroblocks than in the case they are contiguous.

However, according to our experience, in the case of medical video error concealment is not necessarily beneficial, since it may hide important irregularities present in the original video.

For this reason, in this paper we consider FMO as a means to perform ROI implementation in H.264 and not with the purpose of error concealment.

The standard includes seven modes to map macroblocks (MBs) to a slice group and we will consider in the following the explicit mode (Type 6), allowing the user to associate each of the macroblocks to a slice group independently. The pattern information is included in the Picture Parameter Set (PPS).

The FMO tool has already been used by a few authors for the purpose of ROI definition and unequal error protection. In [33] the authors propose a transcoding scheme to perform unequal error protection based on the information available at the output of the entropy coder. Unequal error protection is performed here in the transform domain and context/content information is not considered for the unequal error protection strategy: the most relevant macroblocks in each frame are selected solely based on the distortion introduced at the decoder if the macroblock is lost. In [34] a novel technique to represent ROIs using FMO is proposed, together with a rate control technique to improve the picture quality in ROI. In [35] the importance of every macroblock is calculated based on its influence on the current frame and future frames and macroblocks with the highest impact factor are grouped together in a separate slice group using the flexible macroblock ordering feature of H.264/AVC. The authors suggest that their results could underpin the design of an unequal error protection strategy.

2.5. Unequal Error Protection and Cross-Layer Design for Wireless Video Transmission. Due to the characteristics of video coding methodologies and standards [27, 36], it has been shown that joint source and channel coding/decoding techniques (JSCC/D) are beneficial to wireless video transmission [21]. Although source coding and channel coding are usually treated separately, JSCC/D techniques allow improvements in end-to-end video quality through the joint design of source coding on one side and channel coding and modulation strategies on the other. More in general, the different layers of the standard transmission protocol stack can be jointly designed, according to a paradigm that becomes to be known as cross-layer design [37]. Despite the demonstrable advantages in end-to-end video quality, there are few studies addressing the use of the cross-layer and JSCC/D approach for mobile telemedical applications [13, 14, 20, 21].

Examples of cross-layer methodologies include: rate control [38, 39], to adapt the source coding rate to the network and channel conditions; rate-distortion optimized streaming of packetized media [40]; unequal error protection. Since video packets may contribute differently to the overall video quality, unequal error protection (UEP) [41] is a natural way of protecting transmitted video data. The idea is to allocate more resources to the parts of the video sequence that have a greater impact on video quality, while spending less resources on parts that are less significant.

In [42], an unequal error protection scheme based on rate-compatible punctured convolutional codes is proposed for digital audio. In [43], a priority encoding transmission scheme is proposed to allow a user to set different priorities of error protection for different segments of the video stream. This scheme is suitable for MPEG video, in which there is a decreasing importance among I, P, and B frames. In general, error protection can come from various sources such as forward error correction (FEC), retransmission, and transmission power adaptation. In [44] the authors proposed an UEP scheme for MPEG4 video where different packet partitions were protected with different channel codes. The MPEG4 *data partitioning* tool was exploited and a criterion was proposed in order to avoid passing the otherwise necessary side information about partition lengths. Unequal error protection is also possible taking modulation into account, for example, through appropriate bit allocation over the different subcarriers in multicarrier modulation [45]. An UEP scheme based on different priorities of MPEG4 objects is presented in [29] where shape and texture data are transmitted over different service channels.

In this paper, unequal error protection is performed at the application layer through erasure codes; on one side UEP at the application layer keeps compatibility with the WiMAX standard, since MAC/PHY layers do not require modifications; on the other side, the use of erasure codes allows the recovery of lost packets at the application layer, where the use of bit-error correction codes would be useless, since lower layer protocols remove packets with erroneous bits, unless MAC-lite [46]/UDP-lite protocols are used to allow packets with erroneous bits in the payload to reach the application layer.

3. Problem Formulation and Proposed Transmission Scheme

3.1. ROI Detection. This section presents a detailed formulation of the problem. The reader can refer to Table 1 for a summary of the symbols used. Ultrasound scanners produce conical images where the actual image acquired by the probe sensor is a fan-shaped window over a black background including patient data and in some cases the associated ECG waveform (see Figures 2(a) and 2(b)). The fan-shaped window is the diagnostically useful area and it typically occupies 50%–60% of the area of the full image [47]. The actual size of this fan area in a given ultrasound clip depends on the machine and its settings. After detection of three key points, this area can be modeled as the sector of a circle centered in (a, b) and with radius c, that is, with equation

$$(x-a)^2 + (y-b)^2 = c^2. \tag{1}$$

The automatic detection of the fan area is not trivial, as the position and size of it varies in different frames and from clip to clip. Although a fan-shaped mask can be detected for each frame, we assume the fan area is uniform across all frames. We therefore construct a fan-shaped mask by finding the union of the individual masks identified. It is possible to adopt a similar procedure for clip-to-clip variations, by identifying a "universal" mask.

With the purpose of a context-aware design of the compression and transmission scheme, we identify three ROIs in each ultrasound video sequence (see Figure 2(a)).

ROI 1: Diagnostically most important area identified by the clinician (see, e.g., Figure 2(a));

ROI 2: Fan-shaped sector (see Figure 2(a));

ROI 3: Black background with patient data and in some cases the associated ECG waveform.

In the following, we will also consider ROI 2 and ROI 3 jointly processed, as in Figure 2(b).

In particular, ROI 1 is selected by the medical specialist according to context information such as type of examination and a priori knowledge on the disease to diagnose. ROI 2 can be selected automatically.

We consider two alternative options for compression and transmission of ROI 3.

Table 1: Summary of important symbols used.

Symbol	Definition
m	Slice index
r	ROI index
f	Frame index
$L_{f,r,m}$	Length of slice m in ROI r, frame f
L	Average slice length
$L_{\max}$	Max slice length
r_{tot}	Number of ROIs
f_{tot}	Number of frames per GOP
$I_{f,r}$	Number of slices in ROI r in frame f
$N_{f,r}$	Number of pixels in ROI r in frame f
$\mu_{f,r,m}$	Quantization parameter(s) for slice m, ROI r, frame f
$\pi_{f,r,m}$	Service class
p_E	Generic probability of packet loss
p_L	Residual probability of packet loss after RS coding
$\rho(\pi_{f,r,m})$	Probability of packet loss for service class $\pi_{r,m}$
L_B	Generic mean error burst length (in packets)
q	Transition prob. *lossy* → *lossless* (Gilbert model)
p	Transition prob. *lossless* → *lossy* (Gilbert model)
$\mathcal{L}(\pi_{f,r,m})$	Mean error burst length for service class $\pi_{r,m}$
$B_{f,r,m}$	Encoding bits for slice m in ROI r, frame f
c	RS symbol size
N	RS code block length (in q-ary symbols)
K	RS data block size (in q-ary symbols)
$R_C = K/N$	RS code rate
$R_C(\pi_{r,m})$	RS code rate for service class $\pi_{r,m}$
$R(\pi_{r,m})$	Transmission rate for service class $\pi_{r,m}$
$T_{f,\text{tot}}$	Transmission time per frame
x_i	Luminance of pixel i in original frame
y_i	Luminance of pixel i in received frame

(i) We assume we extract the information in the background prior to transmission. Information in the background is typically text data, for example, about the patient, the instrument used in the examination, and the section of the organ visualized. The associated ECG wave can also be displayed in the background area, with the ECG sample corresponding to the visualized image highlighted with a bar in the waveform. This information can be extracted prior transmission and both text and the ECG waveform can be separately compressed. When DICOM standard is used, such information can easily be separated from the rest of the image.

(ii) We do not extract such information from the background prior to transmission and we transmit ROI 3 as a separate ROI or in the same transmission class as ROI 2.

In the first option, data and ECG waveform are separately encoded. When there is no requirement for high resolution for the diagnosis of a specific disease, ECG waveform is typically sampled at 360 Hz with a resolution of 11 bits per sample. In some cases the information from different (up to eight) channels obtained from different leads is needed. The waveform of a single channel occupies 360 samples/s × 11 bits/sample = 3960 bits/s ≈ 4 kbits/s without compression (for eight channels—12 leads—the rate is about 32 kbps). A channel can be compressed with acceptable quality down to 400 bits/s = 50 Bytes/s (see, e.g., [31] and references cited therein).

When such information is removed and separately encoded, and application layer FEC is adopted, we propose we embed such information in the padding bits needed to have a regular code structure (see Section 3.4).

Note that synchronization between ECG data and ultrasound images is important, in order for the specialist to correlate the visualized image with the corresponding wave in the ECG signal. The ECG signal provides context information to the medical specialist. For instance, it is essential for a specialist to synchronize the measurement of the diameter of vessels to the R-wave spikes in the ECG trace, to eliminate the effects of periodic changes in diameter caused by the normal changes in blood flow with every heartbeat.

3.2. Source Model. We assume that we compress our medical video sequences according to the H.264 video coding standard, with the aid of the Flexible Macroblock Ordering (FMO) tool for encoding separately the different ROIs. We also assume that each ROI r in a frame f is composed of $I_{f,r}$ slices. We assume that different quantization parameters are adopted for each m-th slice for ROI r, $r = 1, 2, 3$, in frame f, that is, quantization parameters are $\mu_{f,r,m}$.

The transmission channel is characterized by a set of parameters (such as packet loss rate, loss burst length, etc.) as specified in Section 3.3. For the sake of generality, we denote the service class associated to mth slice for ROI r in frame f as $\pi_{f,r,m}$, with $r = 1, 2, 3$ in our case. A service class can be intended as a QoS class provided by the underlying network or as a level of protection provided by (possibly unequal) forward error correction. The corresponding probability of packet loss and loss burst length (in packets) are denoted as $\rho(\pi_{f,r,m})$ and $\mathcal{L}(\pi_{f,r,m})$. The transmission rate is $R(\pi_{f,r,m})$.

The total transmission time per frame can be calculated as

$$T_{f,\text{tot}} = \sum_{r=1}^{r_{\text{tot}}} \sum_{m=1}^{I_{f,r}} \left[\frac{B_{f,r,m}\left(\mu_{f,r,m}\right)}{R\left(\pi_{f,r,m}\right)} \right], \tag{2}$$

where $B_{f,r,m}$ represents the encoding bits for slice m in ROI r and r_{tot} is the number of ROIs in the frame. In our case $r_{\text{tot}} = 3$. Note that we do not consider here automatic retransmission request (ARQ) techniques and processing time for FEC is neglected.

In the example results reported in Section 4, we consider the case where we keep quantization parameters constant in a session and we select different service classes for different

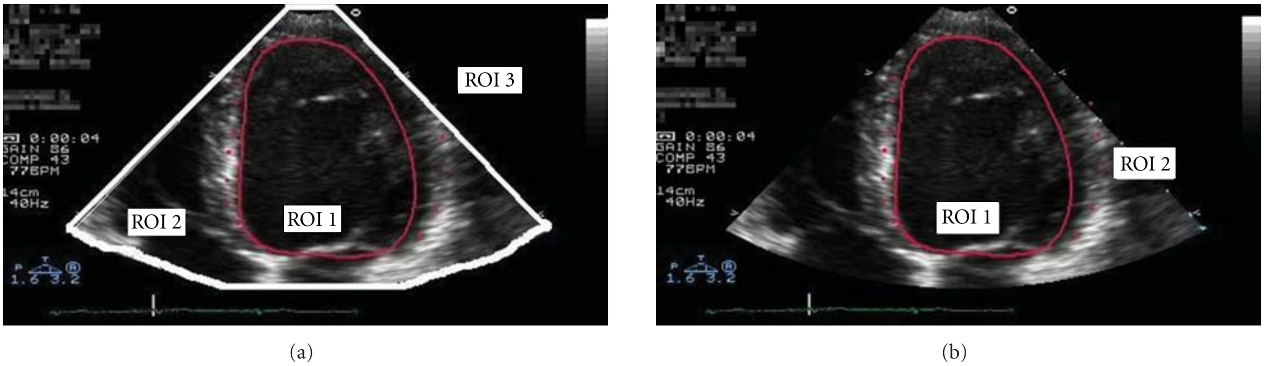


Figure 2: (a) Cardiac ultrasound image with ROIs (manually selected) highlighted. Three regions of interest, (b) Cardiac ultrasound image with ROIs highlighted. Two regions of interest.

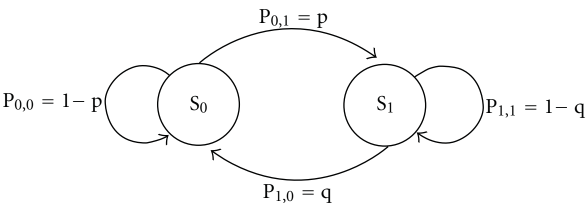


Figure 3: Gilbert channel model.

ROIs through a group of pictures GOP-by-GOP unequal error protection scheme at the application layer. In this case the model simplifies as follows. μ_f: quantization parameter for frame f; $\pi_{f,r}$: service class for ROI r in frame f; $\rho(\pi_{f,r})$: corresponding probability of packet loss; $L(\pi_{f,r})$: corresponding mean burst length.

The total transmission time per frame can be calculated as

$$T_{f,\text{tot}} = \sum_{r=1}^{r_{\text{tot}}} \left[\frac{B_{f,r}\left(\mu_f\right)}{R\left(\pi_{f,r}\right)} \right] \tag{3}$$

and per GOP:

$$T_{\text{GOP,tot}} = \sum_{f=1}^{f_{\text{tot}}} T_{f,\text{tot}}. \tag{4}$$

3.3. Channel Model. We model here the loss pattern as a two-state Gilbert channel. The Gilbert two-state channel model [48] has been widely used in the literature to represent packet loss patterns in wireless fading channels. Two states are considered to represent good and bad channel states in terms of packet errors.

Such a model, depicted in Figure 3, is completely specified by two parameters: the probability of packet loss p_E and the mean burst length L_B. By denoting with S_0 the packet error free state and S_1 the packet error state, the channel state transition probability matrix $\mathbf{P}$ has elements $P_{i,j}$ such that,

$$P_{i,j} = P\left[S(k) = S_j \mid S(k-1) = S_i\right]; \quad i, j \in \{0, 1\} \tag{5}$$

representing the transition probability from state S_i at t_{k-1} to state S_j at t_k.

In particular:

$$\begin{aligned} q &= P[S(k) = S_0 \mid S(k-1) = S_1], \\ p &= P[S(k) = S_1 \mid S(k-1) = S_0]. \end{aligned} \tag{6}$$

The transition matrix is given by

$$\mathbf{P} = \begin{pmatrix} 1-p & p \\ q & 1-q \end{pmatrix} \tag{7}$$

and it is

$$\begin{aligned} p_E &= P[S(k) = S_1] = \frac{p}{p+q}, \\ L_B &= \frac{1}{q}. \end{aligned} \tag{8}$$

3.4. Unequal Error Protection. We present in the following our application layer unequal error protection strategy. The use of Reed-Solomon (RS) codes is described first, the global UEP strategy adopted follows.

3.4.1. RS Codes. We consider the use of Reed-Solomon (RS) codes for application-layer FEC. When FEC is used at the application layer, it is necessary to apply erasure codes across video packets; the WiMAX MAC layer discards the whole MAC frame in the event of an error, that is, the erroneous frame at the receiving MAC is never passed on to the higher layer. Therefore, if RS coding is applied within a single packet at the application layer, the erroneous packet will not be available for error detection or correction at the application layer.

Similar to [49], we apply RS coding across packets using an interleaver, that is, K slices each of length L_m bits are buffered at a matrix interleaver. The first symbol from each of the K slices is sent through an (N, K) RS coder resulting in $N - K$ parity symbols, each of which forms the first symbol of the $N - K$ parity packets. Note that the symbol size in bits depends on the selected value of N, that is, $c = \log_2(N+1)$. This is repeated for the whole slice, resulting in $N-K$ parity packets each of length $L_{\max}$ generated by the RS encoder. Note that actually the slice lengths L_m are not exactly identical and padding bits are needed to obtained equally long packets of length $L_{\max}$.

Each video or parity packet is transmitted via RTP/UDP/IP and an 802.16e MAC frame; if this frame is discarded at the receiving 802.16e MAC layer due to channel errors, this results in a symbol erasure at the RS decoder in the application layer. The RS decoder at the application layer can correct up to $N-K$ packet losses out of N packets over which the RS coding was applied.

This FEC scheme introduces delay due to two events. First, the interlacing operation requires that K slices are accumulated to begin the RS(N,K) coding operation. Second, once K packets are available, generating the redundant packets by applying the RS code involves data processing delay. Due to the high hardware speeds currently available and the possibility to perform encoding in parallel; the latter delay is very limited and we can only consider the time delay involved in having to wait for K packets.

Note that, since the RS code is systematic, it is not necessary to buffer packets to form RS codewords, but the information symbols can be transmitted directly if a local copy is kept to form the parity check symbols. These computed parity check symbols can then be sent immediately after the information symbols, eliminating interlacing delay at the transmitter. The total interlacing delay would then be the delay at the receiving end alone.

Every data block has its own block sequence number, which is useful at the receiver side, since it provides the RS decoder with the position of the lost block. The RS decoder can then recover up to $(N-K)$ lost blocks with this position information instead of recovering $(N-K)/2$ lost blocks without the position information. The residual loss probability in case of independent packet losses is

$$p_L = \frac{1}{N}\sum_{i=t+1}^{N} i\binom{N}{i} p_E^i (1-p_E)^{N-i}, \tag{9}$$

where $t = N-K$ when erasures are considered and information on the position of the erasures is available. For the adopted Gilbert-model the probability of packet error and burst length after FEC can be calculated following the analysis in [50].

If at least K out of N packets are correctly received, the underlying video information can be correctly decoded. Otherwise, none of the lost packets can be recovered by the receiver. This provides resiliency against a maximum packet loss rate of $p = (N-K)/N$ when considering that even FEC packets may be affected by loss. Thus, based on averaged packet loss rate (p_E) measurements such as that provided by RTCP feedback, it is possible to dynamically adjust the redundancy amount $h = N-K$ as $h = p_E K/(1-p_E)$. When a decoding failure happens, there are $(N-i) < K$ correctly-received packets including both video and parity packets possibly. We utilize these video packets if there is any for the video decoding; on average, $(K/N)(K-i)$ packets out of $(N-i)$ correctly-received packets should be video packets.

3.4.2. Context Adaptive UEP Strategy. We propose to provide a high protection to the most significant ROI for the purpose of diagnosis (ROI 1) and a lower protection to ROI 2 and the background. Patient data/ECG can either be transmitted as data and compressed ECG in padding bits of ROI 1 and thus strongly protected, or transmitted in ROI 2.

We propose RS coding is performed GOP by GOP; an RS block will include data from no more than one GOP.

For the selection of the RS block size, the erasure correction capability of the code and the slice size have to be defined first. The selection of slice size $L_{f,r,m}$, when slices are not separated in smaller packets at lower layers, is linked to the network and channel characteristics. In the following we will assume that each ROI is encoded in one slice of length $L_{f,r}$. We build an RS block structure of size $K \times L_{\max}$, where rows are made of symbols from slices and padding bits to reach the length $L_{\max}$, and columns, with data in groups of bits (RS symbol), represent the RS data blocks. $L_{\max}$ is a value which is fixed GOP by GOP depending on the size of the slices in the GOP. The block is simply built by arranging the slices (+ padding bits) as the rows of the RS block until either the suggested value of K rows is reached or the slices belonging to a GOP are terminated. After RS coding the structure has size $N \times L_{\max}$ due to the presence of $N-K$ parity packets.

Note that, with the assumptions above, the MAC PDU size is

$$L_{\text{PDU}} = L_{\text{MAC.header}} + L_{\text{CRC}} + L_{\text{RoHC.header}} + L_{\max}. \tag{10}$$

The selection of the coding rate K/N depends on the characteristics of the channel/the network of the video sequence and of context information and the rate could be adapted dynamically GOP-by-GOP in order to adapt to the conditions of the network.

Instead of considering models for the impact of losses in the different regions on the global distortion, as typically done, in this case we give priority to context information for taking decisions on the protection rate, the relative importance of the region of interest with respect to the background is different for different types of examinations and we propose that this weight is provided by the clinician and considered for the selection of the protection rate of the different ROIs.

After application layer unequal error protection, the total number of bits per frame is

$$B_{f,\text{tot}} = \sum_{r=1}^{r_{\text{tot}}}\left[\frac{B_{f,r}(\mu_f)}{\alpha R_C(\pi_{f,r})}\right] \tag{11}$$

and per GOP

$$B_{\text{GOP,tot}} = \sum_{f=1}^{f_{\text{tot}}} B_{f,\text{tot}}, \tag{12}$$

Table 2: Video coding simulation parameters.

Encoder/Decoder Parameter	Value
Encoder/Decoder	JM reference software codec Version 16.0
Profile	Baseline profile
Test sequences	Guillaume-us
No. of frames	70
Resolution	480 × 256
GOP size	15 (IPPP. . .)
Quantization parameters	30/33
Reference frames	1
Entropy coding	CAVLC (Content Adaptive Variable Length Coding)
Decoder error concealment	JM-FC (JM-Frame Copying)

where the factor $0 < \alpha < 1$ takes into account the overhead due to padding bits in the RS code matrix organization, and f_{tot} is the number of frames in the GOP.

3.4.3. Error Concealment. It is common practice in video transmission to "conceal" the effect of errors at the receiver side by, for instance, interpolating from neighbouring data in time and space. In the medical field, this practice may not be desirable when a medical doctor is performing a diagnosis. Such concealment practice could be misleading since in this case the specialist cannot factor into his or her decision an awareness of missing and potentially important data.

For this reason, we propose that concealment is applied seamlessly only in ROI2 and ROI3 in order to smooth the not diagnostically important ROIs. Although concealment is applied in ROI1, we propose to inform the specialist that a specific MB has been concealed by highlighting concealed MBs in the portion of the video frame belonging to ROI1. It is in fact important that the specialist can assess his/her confidence on the diagnosis.

4. Implementation and Results

4.1. Simulation Scenario. The ultrasound video clips used in our experiments are cardiac ultrasonography sequences, partly collected from a Hospital and partly from public databases.

The acquired medical video sequence is encoded according to the H.264 standard [36] with the parameters reported in Table 2.

Groups of slices are organized with the aid of the flexible macroblock ordering tool, in order to have separate groups of slices for different ROIs. Information about the shape of the different ROIs is stored in the Picture Parameter Set.

The encoded image stream is then encoded through RS codes and delivered via RTP/UDP/IP.

We assume robust header compression (RoHC) is adopted to reduce the overhead due to packetization headers and that RTP/UDP/IP headers are compressed via RoHC to three bytes.

The main Radio Access Network parameters of the reference testbed [51] are shown in Table 3. Measurement conditions and measurement results from [51] are reported for convenience in Tables 4 and 5, respectively.

We consider a vehicular environment, in order to simulate ultrasound video transmission to/from an ambulance. This is the case where immediate access to ultrasound examinations located in the hospital database is needed, and where the examination is performed in an ambulance through a portable ultrasonographer and the relevant video stream is transmitted in real time to the specialist in the hospital.

Table 3: WiMAX RAN system parameters.

Parameter	Value
Channel bandwidth	5 MHz
Carrier frequency	3468.5 MHz and 3568.5 MHz
Number of subcarriers	512
Number of used data subcarriers	360
Cyclic prefix	1/4 symbol duration
Frame length	5 ms
Channel Coding	Turbo Codes
Possible modulation and coding schemes	QPSK 1/2, 16 QAM 1/2, 64 QAM 1/2
ARQ	No ARQ scheme
Number of BS antennas	2
BS antenna	type 4 array antenna
BS antenna height	22 m
BS antenna gain	17 dBm
BS transmission power	35 dBm
BS antenna azimuth	6° and 276°
MS antenna gain	2 dBi
MS transmission power	23 dBm

Table 4: Vehicular measurement parameters.

Distance to BS antenna	281 m–500 m
Scenario	Sub-Urban
Mobile speed	50 km/h
Max. channel bandwidth	500 kbps
Packets per second	38

Table 5: WiMAX measurement results considered for simulation.

MIN Delay [s]	MAX Delay [s]	Average Delay [s]	Max Packet Loss Burst Length	Packet Loss [%]
0.017273	0.184955	0.047212	28	10.14

Focusing on the latter scenario, we consider uplink data transmission. In particular the Gilbert channel model parameters are selected according to the measurements in Table 5. The mean packet loss rate is set to $P_L = 10^{-1}$. The measurements only report the maximum packet-loss burst length. By assuming a geometric distribution for the burst length, we estimate the mean packet-loss burst length as $L_B = 5$; in this case according to the geometric distribution the probability of having a packet-loss burst length higher than the measured maximum value is of the order of 10^{-4}. Note that measurements are done by transmitting a number of packets of the order of 10^4.

We compare the following strategies for application layer (unequal) error protection (see Table 5).

(1) No application layer protection; in this case all the available bitrate is used for representing the video sequence.

(2) Application layer equal error protection (EEP): in this case a higher protection is uniformly provided to the bitstream, resulting in a higher robustness in bad channel/network conditions, but in a reduced global quality when channel/network conditions are good. RS(31,23).

(3) Application layer ROI-based unequal error protection: similar as in the case above, this scheme results in a higher robustness in bad channel/network conditions, but in a reduced global quality when channel/network conditions are good. In this case, however, the redundancy is exploited to protect the most important information from the point of view of the diagnosis and an improved quality in terms of probability to perform a correct diagnosis is expected also when channel conditions are bad.

(4) Application layer ROI-based and prediction-based unequal error protection; this scheme results in a higher robustness in bad channel/network conditions, but in an even more reduced global quality when channel/network conditions are good. In this case, the redundancy is exploited to protect the most important ROI from the point of view of the diagnosis and the most important information for motion compensation prediction (I frames). An improved quality in terms of probability to perform a correct diagnosis is expected also when channel conditions are bad.

4.2. Performance Evaluation Metrics. In medical applications, the target of the optimization of the transmission system should not be the minimization of distortion in terms of mean square error (or equivalently the maximization of the peak signal-to-noise ratio, PSNR), but the maximization of the probability of performing a correct diagnosis based on the received video sequence. Although not designed for this purpose, according to preliminary studies [13, 52] the structural similarity metric (SSIM) [53] better meets this criterion and for this reason we consider in this paper SSIM in addition to the well-known PSNR. Although the performance assessment of such a scheme should be done through subjective metrics, results are presented in terms of the aforementioned well known objective metrics in order to allow easy comparison with results obtained by other authors and to give an indication of the local distortion achieved in different ROIs.

We consider local distortion as in the following:

$$\mathrm{MSE}_{\mathrm{ROI}r} = \frac{1}{N_r}\sum_{i=1}^{N_r}(x_i - y_i)^2,$$
$$\mathrm{PSNR}_{\mathrm{ROI}r} = 10\log_{10}\frac{255^2}{\mathrm{MSE}_{\mathrm{ROI}r}}, \tag{13}$$

where N_r is the number of pixels in ROI; r, x_i and y_i represent the luminance of pixel i in the original and in the corrupted frame, respectively.

We then consider a slightly modified version of the SSIM metric in [53]. The SSIM index, as shown in (14), can be written as the product of three independent contributions, representing the luminance information, the contrast information, and the structural information. With $\mathbf{x}$ and $\mathbf{y}$ indicating image signals in the reference and received image,

$$\mathrm{SSIM}(\mathbf{x},\mathbf{y}) = l(\mathbf{x},\mathbf{y}) \cdot c(\mathbf{x},\mathbf{y}) \cdot s(\mathbf{x},\mathbf{y}), \tag{14}$$

where the luminance comparison is represented by the term

$$l(\mathbf{x},\mathbf{y}) = \frac{2\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1} \tag{15}$$

and for the contrast comparison

$$c(\mathbf{x},\mathbf{y}) = \frac{2\sigma_x\sigma_y + C_2}{\sigma_x^2 + \sigma_y^2 + C_1}. \tag{16}$$

The structural comparison term $s(x, y)$ is

$$s(\mathbf{x},\mathbf{y}) = \frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3}. \tag{17}$$

In the expressions above C_1, C_2, and C_3 are appropriate constant values. At each coordinate, the SSIM index is calculated within a local window. As in [53], we use a 11×11 circular-symmetric Gaussian weighting function w_i, with standard deviation of 1.5 samples, normalized to sum to unity: $\sum_i w_i = 1$. The statistics are thus defined as

$$\mu_x = \frac{1}{N}\sum_{i=1}^{N} w_i x_i,$$
$$\sigma_x^2 = \frac{1}{N-1}\sum_{i=1}^{N} w_i(x_i - \mu_x)^2, \tag{18}$$
$$\sigma_{xy} = \frac{1}{N-1}\sum_{i=1}^{N} w_i(x_i - \mu_x)\left(y_i - \mu_y\right).$$

We then define the MSSIM metric for ROIr as

$$\mathrm{MSSIM}_{\mathrm{ROI}_r}(\mathbf{X_r},\mathbf{Y_r}) = \frac{1}{M}\sum_{j=1}^{M}\mathrm{SSIM}\left(\mathbf{x_{r,j}},\mathbf{y_{r,j}}\right), \tag{19}$$

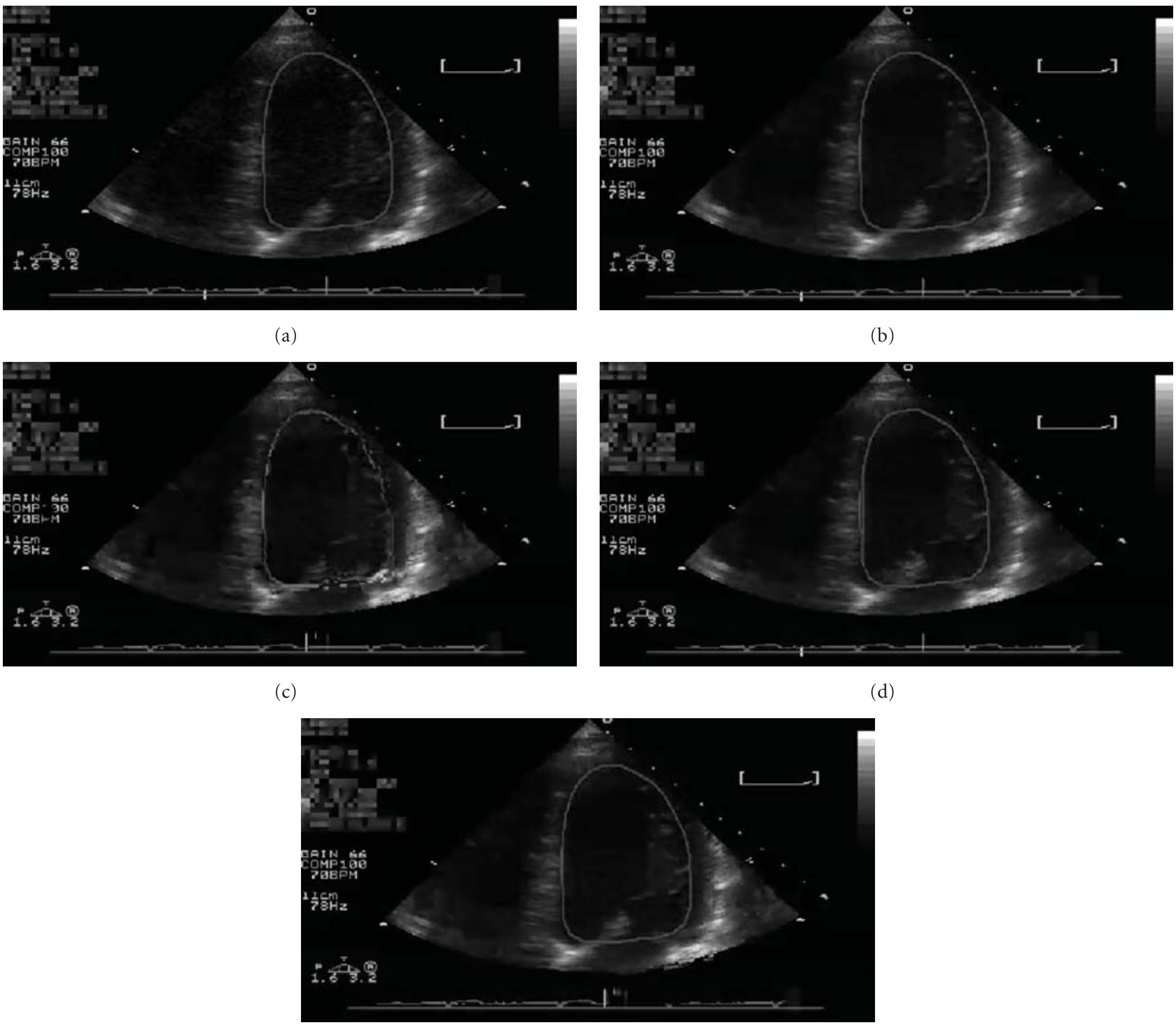
where M is the number of local windows in ROI r and j is the local window index.

Table 6: Application-layer unequal error protection strategies adopted.

		Source bitrate	ROI 1 frames I	ROI 2 frames I	ROI 1 frames P	ROI 2 frames P
1	No application layer FEC	480 kbps	—	—	—	—
2	Application layer EEP	300 kbps	RS(31,23)	RS(31,23)	RS(31,23)	RS(31,23)
3	Application layer UEP based on ROIs	300 kbps	RS(31,16)	—	RS(31,16)	—
4	Application layer UEP based on ROIs and prediction	300 kbps	RS(31,22)	RS(31,22)	RS(31,22)	—

Table 7: Video quality results.

	UNCODED			EEP			UEP 1			UEP 2		
	Overall	ROI 1	ROI 2	Overall	ROI 1	ROI 2	Overall	ROI 1	ROI 2	Overall	ROI 1	ROI 2
PSNR (dB)	33.11	30.94	34.01	34.63	30.92	36.12	34.15	33.26	33.85	34.95	33.06	35.65
SSIM	0.89511	0.81503	0.89953	0.89881	0.81443	0.91568	0.89845	0.85342	0.90887	0.90424	0.84647	0.9144



(a) (b) (c) (d) (e)

Figure 4: Visual results—Frame no. 44 of the test sequence. (a) Original; (b) Uncoded (Scheme 2 in Table 6); (c) EEP (Scheme 1 in Table 6); (d) UEP 1 (Scheme 3 in Table 6); (e) UEP 2 (Scheme 4 in Table 6).

4.3. Numerical Results. Numerical results obtained in the conditions described above, and summarized in Table 6, are reported in Table 7. PSNR and SSIM values are average values over the different frames of the sequence. Local PSNR and SSIM values are also reported, as defined in Section 4.2.

Note that the quality of the diagnostically important region of interest is lower than the quality of the background in the unprotected case, due to the different complexity and the use of the same quantization parameter for the different ROIs.

A uniform protection scheme at the application layer (EEP) increases the total quality of the sequence, but it fails in sensibly increasing the quality of the most important ROI for the diagnosis. We highlight here that the schemes where FEC is applied at the application layer are compared with an uncoded scheme where a higher bitrate is adopted in source encoding, in order to allow a fair comparison.

Both the UEP schemes manage to improve the quality of ROI 1, at the expense of a slight decrease in quality in the remaining part of the images. The scheme UEP 1 provides a slightly higher quality for ROI 1, both in terms of PSNR and SSIM. Scheme UEP 2 provides an improvement of about 1 dB in PSNR with a decrease in quality with respect to scheme UEP 1 of only 0.2 dBs in ROI 1 and it can be preferable in some scenarios as also confirmed by subjective tests.

Visual results are reported in Figure 4. The sequence corresponding to image [e] is the one selected by the medical specialist involved in the study as the one best keeping diagnostic quality.

5. Conclusion

We have proposed in this paper a context-aware transmission strategy for diagnostic-quality ultrasound video transmission over WiMAX systems. Context, in terms of regions of interest (ROI) in a specific session, is taken into account for the identification of multiple regions of interest, and compression/transmission strategies are tailored to such context information. We have presented a methodology based on H.264 medical video compression and FMO for ROI identification. Two different unequal error protection methodologies, providing higher protection to the most diagnostically relevant data, are compared. Results show that the proposed scheme allows an improvement for the diagnostic region of interest of about 3 dBs in PSNR and 0.31 in SSIM with respect to the case where such an approach is not adopted, still obtaining a small improvement in quality in the rest of the image (0.8–1.6 in PSNR for UEP 1 and UEP 2, resp.). This methodology is simple to implement and standard compatible.

Acknowledgment

This work was partially supported by the European Commission (FP7 Project OPTIMIX INFSO-ICT-21462).

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 507071, 5 pages
doi:10.1155/2010/507071

Research Article

Vascular Neurology Nurse Practitioner Provision of Telemedicine Consultations

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Received 9 November 2009; Revised 20 April 2010; Accepted 22 June 2010

Academic Editor: Athanasios Demiris

Objective. The objective was to define and evaluate a role for the Vascular Neurology-Nurse Practitioner (VN-NP) in the delivery of telemedicine consultations in partnership with a vascular neurologist. *Methods*. Prospective stroke alert patients at participating hospitals underwent a two-way audio video telemedicine consultation with a VN-NP at a remotely located stroke center in partnership with a vascular neurologist. Demographic information, National Institutes of Health Stroke Scale (NIHSS) scores, diagnoses, CT contraindications to thrombolysis, thrombolysis eligibility, and time interval data were collected. The inter-rater agreement between VN-NP and vascular neurologist assessments was calculated. *Results*. Ten patients were evaluated. Four were determined to have ischemic stroke, one had a transient ischemic attack, two had intracerebral hemorrhages, and three were stroke mimics. Overall, three patients received thrombolysis. The inter-rater agreement between VN-NP and vascular neurologist assessments were excellent, ranging from 0.9 to 1.0. The duration of VN-NP consultation was 53.2 ± 9.0 minutes, which included the vascular neurologist supervisory evaluation time of 12.0 ± 9.6 minutes. *Conclusion*. This study illustrated that a stroke center VN-NP, in partnership with a vascular neurologist, could deliver timely telemedicine consultations, accurate diagnoses, and correct treatments in acute stroke patients who presented to remotely located rural emergency departments within a hub and spoke network. VN-NPs may fulfill the role of a telestroke provider.

1. Introduction

The purpose of this preliminary study was to define, demonstrate, and evaluate a role for the vascular neurology nurse practitioner (VN-NP) in the delivery of telemedicine consultations in partnership with a vascular neurologist in the context of an established hub and spoke stroke telemedicine network. NPs, physician assistants (PAs), and other physician extenders are no longer being relegated to subservient roles in health-care delivery. They are assuming an ever-increasing level of responsibility in patient care. With technological enablers, such as telemedicine, physician extenders' future roles as specialty caregivers in rural communities will grow. Examples of physician—NP telemedicine partnerships already exist in rural emergency medicine, but none describe the potential role of a VN-NP telemedicine provider responding to cases of acute stroke.

Physician extenders and midlevel providers have practiced emergency medicine for 25 years or more [1]. In the United States, it is estimated that NP and PA are involved in 1.8% and 6.5%, respectively, of emergency department consultations [2]. Nearly half of all emergency departments employ midlevel providers [3]. Historically, emergency medicine midlevel providers were positioned in the hospital; when or if, supervision was necessary, emergency physicians and/or medical or surgical specialists were consulted. With telemedicine, an NP positioned in an emergency department could consult a remotely located physician. For example, in the published program, "TelEmergency for rural hospitals," emergency NP collaborated with remote TelEmergency physicians to treat patients [4]. The NP was required to have specific qualifications, including master's degree, certification as a family NP with an unrestricted license, and state license eligibility [4]. In the TelEmergency system, the cost of 24/7 NP and TelEmergency physician staffing partnership was US $53,000 per month per spoke, compared with an estimated US $72,000 per month for a traditional physician staffing model [4]. The NP and physician partnership system allowed participating spoke hospitals to provide emergency services equivalent to a physician-only model while realizing significant cost savings. In TelEmergency, stroke presentation was a top-ten most common complaint category in the patients over 75 years of age, representing 6% of the diagnoses. Overall patient satisfaction with a TelEmergency program was very high, 94% indicating comfort in the system and practitioner partnership [4]. Other countries, including Australia, England, Scotland, Netherlands, and Canada have adopted midlevel providers in rural and remote regions to address workforce shortage [5]. The midlevel providers have provided safe, high-quality, and cost-effective care. There are many published examples of both NPs and PAs practicing telemedicine [6–9].

In vascular neurology, it is notable that there is a rural metropolitan disparity in acute stroke care with a shortage of vascular neurologists and an aging-aware population. There is more public pressure than ever before. Healthcare organizations are answering by establishing primary stroke centers. However, acquiring the needed work force remains challenging. One solution would be to utilize specialized NPs or PAs.

The primary objective of this preliminary study was to establish the feasibility of a VN-NP and a supervising vascular neurologist partnership to respond, emergently, to telestroke hotline activations in a single hub, multirural spoke hospital telestroke state network. A secondary objective was to assess agreement between VN-NP and vascular neurologist over the NIHSS score, diagnosis (stroke or nonstroke), head CT interpretation (radiological contraindication to thrombolysis or not), and overall thrombolysis eligibility (yes or no). Thirdly, the encounter time (minutes) intervals of the VN-NP vascular neurologist consultative partnership experience were evaluated.

2. Methods

A fully operational single-hub, multirural spoke hospital telestroke network existed in Arizona, United States of America. A description of how the early hub and spoke network was established with descriptions of the technological factors, information technology, security, data encryption, the audio visual (AV) camera system, and technique, and prospective reliability have already been published [9–14].

The hub stroke team (on-call 24 hours per day, 7 days per week) was contacted directly by a ring-central operated alphanumeric group pager system or smart phone when a patient with acute stroke symptoms presented at the spoke emergency department. When on-call with the stroke team (1 week per month) the designated hub VN-NP telephoned the applicable spoke emergency department and spoke briefly with the spoke emergency physician in order to determine patient eligibility status for AV consultation. The published STRokE DOC AZ TIME and STARR AV telestroke consultation algorithm was replicated [10, 15]. Eligible consented patients underwent consultation. The hub VN-NP established audio and video contact with the spoke site and immediately acquired a medical history from patients and all the accompanying relatives, supplemented by verbal and written reports from emergency medical systems (EMS), physicians, and nursing staff.

Following the history acquisition, the VN-NP, certified in National Institutes of Health stroke scale (NIHSS) examination, performed the evaluation with the aid of healthcare provider staff at the spoke site. Other relevant elements of the examination were performed by, or reported to, the NP as appropriate. Diagnostic test results were reported to the VN-NP by the spoke emergency physician, either verbally or by electronic-fax (e-fax). The e-fax is a system in which faxed material is received via e-mail. Head computed tomography (CT) images were viewed by the hub VN-NP with digital imaging and communications in medicine (DICOM) viewer. The hub VN-NP completed a prespecified consultation report form, which included acute time intervals, eligibility criteria checklist for thrombolysis, NIHSS scoring, CT evaluation checklist, and laboratory findings. Clinical deficit and functional scale scores (including the NIHSS and prestrike- and poststroke- modified Rankin scale (mRS) score) were calculated by the VN-NP with the information provided by the bedside emergency physician or other healthcare providers. After a review of the history, the examination findings, stroke scales, head CT interpretation, laboratory results, and electrocardiogram, the VN-NP communicated with the supervising hub vascular neurology consultant.

Communication between the VN-NP and vascular neurologist was generally by telephone as they were not in the same location. In every consultation the VN-NP presented a synthesis of the case, the diagnosis, and a recommendation regarding patient eligibility for intravenous thrombolysis to the supervising consultant. The consultant, also certified in the NIHSS examination, established audio and video contact with the spoke site and was free to repeat, or request a repeated, examination item and could interact with patient, relatives, witnesses, and emergency nurses and review head CT. Within approximately 10 minutes, the consultant notified the VN-NP of whether or not there was agreement regarding the NIHSS score, CT interpretation, diagnosis, and treatment recommendation. Once consensus was reached (within approximately 5 minutes), the VN-NP presented the recommendation regarding patient diagnosis and eligibility for intravenous thrombolysis to the spoke emergency physician. The VN-NP dictated a consultation summary note, and the consultant added a brief supervisory note. Once transcribed, both were transmitted to spoke emergency department by e-fax. Copies were maintained in the hub and spoke healthcare records.

Hub hospital stroke center providers included a Neurovascular Education and Training in Stroke Management and Acute Reperfusion Therapy (NET SMART) NP graduate and five vascular neurologists. Equipment included internet-enabled desktops and laptops with cameras for hub providers and telemedicine platform systems at remote emergency departments [16]. The software enabled site-independent access to two-way audio and high-resolution video, over

Table 1: Demographic information, diagnoses, and thrombolysis eligibility.

	VN-NP Telemedicine Algorithm ($N = 10$)
Gender (% Female)	50.0
Age (Mean, Years)	70.8
NIHSS Score (Mean)	11.6
Ischemic Stroke (%)	40.0
Intracerebral Hemorrhage (%)	20.0
TIA (%)	10.0
Stroke Mimic (%)	30.0
CT contraindication to thrombolysis (%)	20.0
Thrombolysis Administered (proportion of consultations)	30.0

standard internet connections (BF Technologies, San Diego, CA, USA).

Data from ten prospective VN-NP telestroke consultations, supervised by a vascular neurologist, were collected during the interval from November 2008 to November 2009. The study was approved by each of the participating spoke hospital institutional review boards (IRB) and also by Mayo Clinic IRB, with authorization for central oversight.

Table 2: VN-NP and Vascular Neurologist Inter rater Agreement.

Assessment	Kappa (95% CI, if applicable)
NIHSS Score	0.859 (0.734 to 0.984)
Stroke Diagnosis	1.0
CT contraindication to thrombolysis	1.0
Thrombolysis eligibility	1.0

3. Statistical Analysis

This preliminary paper was principally a feasibility study. The study sample size was 10 cases. Analyses included mean and standard deviation of time categories and kappa coefficient for inter rater agreement.

4. Results

Table 1 displays basic demographic information, severity of deficit, diagnosis, CT observation, and thrombolysis eligibility of this study cohort. The VN-NP telestroke consultation patients did not differ substantially, in characteristics, from those patients in similar trials [10, 12]. The VN-NP telestroke consultation patients were broadly representative of typical patients seen by emergency stroke teams, for example, similar proportions of ischemic and hemorrhagic stroke, transient ischemic attack, and stroke mimics. Thirty percent of the VN-NP consultation patients were determined to have ischemic stroke and were eligible for thrombolysis, similar to the proportion in other telestroke trials [10, 12]. The inter rater agreement between VN-NP and vascular neurologist (Table 2) was excellent for NIHSS score, diagnosis, head CT interpretation, and overall thrombolysis eligibility.

5. Discussion

There are many facets of this small study worthy of discussion, including: comparing time intervals between telemedicine studies, feasibility, scope of practice of mid level providers, neurovascular specialty training, and future considerations.

The time intervals of the VN-NP vascular neurologist consultative partnership (Table 3) were similar to those of previously published traditional vascular neurologist service provision in telestroke trials in the same network (STRokE DOC AZ) [7] and a comparable network in a neighboring state (STRokE DOC) [12]. Compared to physician-only telestroke consultations, the VN-NP algorithm resulted in approximately 10 minutes faster call-to-neurology exam and 10 to 20 minutes faster consent-to-neurology exam intervals, but 20 to 30 minutes slower decision-to-rt-PA interval. The VN-NP appeared to respond quickly to telestroke alert calls from spoke hospitals, progressing swiftly from the emergency alert to starting the consultation. On the other hand, the decision (for tPA eligibility) to tPA administration was relatively long, 45 minutes, in this study. The result represents only three (of 10 total) thrombolysed subjects. The sample was very small. Events needing to occur between VN-NP decision and thrombolysis include: supervising vascular neurologist evaluation, consensus, communication with emergency physician, communication with patient/family, pharmacy order for tPA, drug preparation, and then administration. Occasionally elevated blood pressure required treatment before tPA was administered. Despite the added complexity of two neurology providers assessing each patient and communicating with one another, the overall time intervals of call-to-decision and consent-to-rt-PA were similar to intervals reported by STRokE DOC trials [12, 15]. The supervising vascular neurologists required an average 12.0 minutes to assess each shared telestroke case, in contrast to an average requirement of 58.3 to 64.7 minutes per case without VN-NP partnership [12, 15]. Even the cumulative total of VN-NP plus vascular neurologist time requirement (65.2 minutes) was not substantially different from the published time required by a solo vascular neurologist (58.3 to 64.7 minutes) [12, 15].

Table 3: Consultation time intervals.

Time Interval	VN-NP Telemedicine Algorithm (mean and standard deviation, minutes)
Onset to Door	32.3 ± 20.5
Onset to Call	42.8 ± 21.2
Onset to Lab	110.5 ± 12.0
Onset to Decision	112.6 ± 31.1
Onset to rt-PA	159.0 ± 8.5
Door to Call	19.6 ± 18.7
Door to Consent	39.8 ± 26.0
Door to Lab	75.0 ± 32.4
Door to Neuro Exam	54.2 ± 15.1
Door to CT Reading	78.2 ± 23.4
Door to Decision	69.6 ± 9.6
Call to Consent	21.0 ± 10.8
Call to Neuro Exam	31.5 ± 11.5
Call to Decision	53.2 ± 9.0
Consent to Neuro Exam	9.0 ± 16.8
Consent to Decision	30.7 ± 19.3
Consent to rt-PA	67.0 ± 30.5
Decision to rt-PA	45.5 ± 21.9

Definitions: Onset:stroke symptom onset time or the time the subject was last known to be at baseline state; Door:emergency department triage time; Lab:time lab results reviewed; Decision:time that thrombolysis eligibility was determined; rt-PA:time of IV rt-PA administration; Consent:time of subject or representative written consent; Neuro Exam:time that the NIHSS evaluation started; CT Reading:time that CT was interpreted.

The results from this preliminary study demonstrated the feasibility of establishing a VN-NP and a supervising vascular neurologist partnership to respond, emergently, to telestroke hotline activations in a single hub, multirural spoke hospital telestroke state network compared to those of published traditional vascular neurology consultant telestroke service provision in the same network (STRokE DOC AZ) and a comparable network in a neighboring state (STRokE DOC) [12, 15]. This bodes well in a relatively busy telemedicine network hub responding to many, and sometimes, simultaneous stroke alerts.

The algorithm proposed is built upon the success of midlevel providers practicing emergency medicine and telemedicine, but there is a fundamental difference. In our study algorithm, both the VN-NP and the vascular neurology physician specialist were practicing telemedicine remote from the emergency patient. The concept of telestroke is already a decade old but its broad and growing utilization is relatively novel. Elements of this consultative modality remain controversial, debated, researched and pose limitations and obstacles to wide-scale adoption. We believe this to be the first published description of VN-NPs as telestroke providers. We anticipate the continued, and growing, need for stroke providers and suspect that vascular neurologist numbers, alone, will not suffice. Stroke-trained midlevel practitioners, together with telemedicine, may provide a practical and cost-effective solution.

In this study, it is important to clarify the scope of practice for NPs and PAs. The healthcare organization, Mayo Clinic, where this study took place, spans three states and employs both NPs and PAs. The policies regulating the scope of practice for NPs and PAs are consistent system wide and are collectively classified as Advanced Midlevel Practitioners (AMLPs). Many healthcare organizations have policies governing the practice of AMLPs that may differ from the state boards.

A study funded by the National Center for Health Workforce Analysis bureau of Health Professions compared changes in the professional practice for NPs, PAs, and certified nurse midwives from 1992 and 2000 [17]. The PA is a physician extender whose scope of practice is determined by the supervising physician who delegates or assigns duties within their specialty. However state laws and regulations play a significant role as well [18] whereas in most states NPs are not dependent on upon physician delegation or supervision with autonomy and have full prescriptive rights [19].

In this study the supervision of the NP by the collaborating physician is important. Stroke telemedicine is a new frontier. Recently, vascular neurologists were conducting studies to determine if they could accurately and safely make decisions on the use of thrombolysis for acute stroke utilizing audio-video consultation. The research team determined that a partnership of a physician and NP would be a conservative and safe next step for a pilot study. The results could influence the development of collaborative or solo NP acute stroke telemedicine practices.

Many NPs and PAs are becoming more subspecialized in their practice. The NET SMART-APN is the first-ever fellowship for neurovascular care. It is a federally funded, evidence-based, neurovascular fellowship program supported by the Healthcare Services and Resources Administration. Eighty-one APNs are currently enrolled in the curriculum, and 15 will graduate in 2010. At stroke centers with newly graduated NET SMART APN fellows, the thrombolysis treatment rates have increased substantially [16]. The NET SMART program includes 14 learning modules, with “CT Imaging in Acute Stroke” included as a fundamental topic. The 28-hour module incorporated both online didactic and preceptored training by vascular neurologists and Neuroradiologists with 20 acute stroke cases to be signed off for accuracy. NET SMART graduates who become proficient with telemedicine techniques have all the requisite skills to serve as providers for rurally located stroke patients in the emergency department, the hospital, and during postdischarge followup clinics.

Acute care NPs role in telemedicine practice is expanding. According to the Joint Commission, the medical staff determines which services can be appropriately delivered via telemedicine [20]. All practitioners, including NPs, who diagnose and treat patients using telemedicine technology, are subject to the credentialing and privileging processes of the receiving organization [20]. A receiving organization may elect to use the credentialing information gathered by another JC accredited facility, provided that the receiving organization makes the decisions delineating privileges [20]. The Arizona Board of Nursing does not make reference to NPs and telemedicine. NPs do not require a supervising physician for treating patients in Arizona although they are expected to consult a physician whenever they believe the situation warrants it.

6. Conclusion

This preliminary study was limited, principally by size (10 consultations) and the lack of a direct comparison arm. Nonetheless, the study was the first to demonstrate that a VN-NP, in partnership with a vascular neurologist, could deliver timely telemedicine consultations, accurate diagnoses, and correct treatments in acute stroke patients who presented to rural emergency departments within an established hub and spoke network. Future larger studies on this topic should be designed to compare timeliness, accuracy, decision making, effectiveness, short and long term clinical outcomes, and cost of the VN-NP versus vascular neurologist-only model for acute stroke care in rural community settings. This VN-NP and a telemedicine practice partnership with vascular neurologists may be viable answers to the critical rural-urban disparity of acute stroke management practices.

Disclosures

None of the authors have any conflicts to declare.

Funding

Arizona Department of Health Services and Mayo Clinic Arizona sponsored STRokE DOC Arizona TIME (NCT00623350) and STARR Trial (NCT00829361).

Acknowledgments

The authors acknowledge the Stroke Telemedicine for Arizona Rural Residents (STARR) network, hub and spoke hospitals, investigators, program managers, information technologists, and clinical research coordinators.

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 181806, 11 pages
doi:10.1155/2010/181806

Research Article

Telemedical Support in Patients with Chronic Heart Failure: Experience from Different Projects in Germany

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Received 3 December 2009; Revised 22 March 2010; Accepted 28 June 2010

Academic Editor: Athanasios Demiris

The great epidemiological significance and costs associated with chronic heart failure pose a challenge to health systems in Western industrial countries. In the past few years, controlled randomised studies have shown that patients with chronic heart failure benefit from telemedical monitoring; specifically, telemonitoring of various vital parameters combined with a review of the symptoms, drug compliance and patient education. In Germany, various telemedical monitoring projects for patients with chronic heart failure have been initiated in the past few years; seven of them are presented here. Currently 7220 patients are being monitored in the seven selected projects. Most patients (51.1%) are in NYHA stage II, 26.3% in NYHA stage III, 14.5% in NYHA stage I and only 6.6% in NYHA stage IV respectively. Most projects are primarily regional. Their structure of telemedical monitoring tends to be modular and uses stratification according to the NYHA stages. All projects include medical or health economics assessments. The future of telemedical monitoring projects for patients with chronic heart failure will depend on the outcome of these assessments. Only of there is statistical evidence for medical benefit to the individual patient as well as cost savings will these projects continue.

1. Introduction

In the Western industrial nations, chronic heart failure has great epidemiological significance due to the rising number of patients, particularly elderly ones [1]. This development occurs in addition to the demographic development characterised by low birth rates and an increasingly large proportion of old and very old people. According to the New York Heart Association (NYHA) stage, the prognosis for chronic heart failure is in some cases worse than for various malignant diseases [2].

Due to both, drug therapy (e.g., angiotensin-converting enzyme blockers, AT_1-receptor blockers, aldosterone antagonists, or beta-receptor blockers) and medical devices (e.g., implantable cardioverter-defibrillators—ICD—and biventricular stimulation), the prognosis for chronic heart failure has improved in the past few years [3–5]. Therefore, these component of therapy have been incorporated into the guidelines of national and international specialist societies on the treatment of chronic heart failure [6, 7]. However, incorporating these recommendations, especially optimised drug treatment, into clinical practice has been unsatisfactory [5]. It has been shown that with targeted patient information and education, medication adherence and therefore medical outcomes of patients with chronic heart failure can be improved [8–10].

One of the primary goals of the treatment of patients with chronic heart failure is to avoid rehospitalisation. The number and duration of rehospitalisations due to decompensation of preexisting heart failure are not only of serious impact the patients quality of life, but also pose a large health-economic burden on the health system [11, 12].

The cost for in-patient treatment of patients with chronic heart failure in Germany amounted to 1.7 billion Euros in 2006. This corresponds to about 60% of the overall costs of therapy for heart failure [12].

Thus, the primary goal must be to avoid or shorten renewed and prolonged rehospitalisations. Disease management programmes can reduce the mortality and rate of rehospitalisations and improve the quality of life of patients with chronic heart failure [13, 14]. In this context, questions arise regarding the options and efficiency offered by telemedical monitoring of patients with chronic heart failure. The definition of telemedical applications in this field is not uniform. The scenarios range from telephone support (nurse calls) and the monitoring of symptoms and compliance, to a complex kind of telemedical monitoring using automated transmission of data from medical devices [15–17]. The system used in the European Network Home Care Management System (TEN-HMS) study can now be considered the "classic scenario" for telemedical monitoring of patients with chronic heart failure [18]. This scenario is presented in a modified form in Figure 1.

In addition to the patients and the medical service providers (general practitioner, cardiologist in private practice, hospital), the most important partner in a complex telemonitoring system is the telemedical service centre. All data is collected here and integrated into the electronic patient records and constitutes the central core of case management. The patients transmit various vital parameters, either at intervals or continuously, to the telemedical service centre. The transmission of the vital parameters can be conducted via telephone or mobile phone. In Germany, one limiting factor seems to be the missing internet access, particularly in primary care practices.

The relevant monitoring parameters are heart rate, ECG (arrhythmias), blood pressure, and body weight. For instance, it was shown in a clinical study that atrial fibrillation worsens the prognosis for patients with chronic heart failure [19]. Body weight monitoring is an important clinical parameter in recognising cardiac decompensation. By regularly monitoring body weight, mortality was significantly reduced in the Weight Monitoring in Heart Failure (WHARF) trial [20]. An increase in body weight after release from hospital is an important predictor of rehospitalisation [21]. In addition, data from cardiac pacemakers, ICDs, or systems for cardiac resynchronisation (biventricular cardiac pacemakers or ICDs) are transmitted by remote control. The telemedical service centre monitors and selects the data. The data are then transmitted to the general practitioner, cardiologist, or hospital, as needed. The individual partners have access to the electronic patient records in accordance with the rules of data protection and with protected passwords. In addition, patients get contacted directly via telephone from the telemedical service centre. During these calls, questions can be asked about symptoms (edema, shortness of breath, etc.) and the medication taken. Furthermore, consultations and structured systematic training sessions on various problems related to heart failure are offered to patients. Thanks to a round-the-clock presence of doctors in the telemedical centre, it is possible to manage emergencies.

In the past few years, much international experience has been gathered in this regard on telemonitoring in patients with chronic heart failure, also in the context of randomised controlled studies. In the following, we report on selected projects in Germany.

2. Presentation of Individual Projects

The German health system has traditionally been structured according to sector, namely, the outpatient and inpatient sectors. Government policy has made various attempts in the last few years to overcome this division to some extent. One important mean to achieve this is contracts for integrated care [22].

In the past few years, a number of, mostly regional, model projects on telemonitoring patients with chronic heart failure have been conducted in Germany. These projects brought forth signs of cooperation between the hospitals and practising physicians, as the providers of medical care, and various health insurance organisations. In addition, providers of telemedical services and industrial partners were included in the cooperation. Table 1 provides an overview of selected telemedical projects for patients with chronic heart failure in Germany.

Currently 7220 patients are being monitored in seven selected telemonitoring projects for patients with chronic heart failure. Most patients (51.1%) are in NYHA stage II, 26.3% in NYHA stage III, 14.5% in NYHA stage I, only 6.6% of patients were in NYHA stage IV, and in 1.6% of the Patients the NYHA stage was unknown.

The selected projects are presented in greater detail in the following sections.

2.1. "HeiTel". The telemedical care of patients with heart failure in the context of the HeiTel project makes it possible, through monitoring, to institute and adjust therapy optimised for the individual patient. The patient transmits by telephone certain prescribed vital parameters (e.g., weight, blood pressure) via modem to the telemedical centre in an automated manner. If individually defined threshold values are not reached or exceeded, an alarm is immediately triggered in the monitoring centre so that therapeutic measures can be started immediately. Independent of any alarm responses, a patient in NYHA stages III-IV is contacted proactively at least once a week, while a stage II patient is contacted at least twice a month; they are asked questions according to a standardised form. The goal of these contacts is to promote medication adherence and to recognize telltale changes in a patient's health status as early as possible. Patients can reach the telemedical centre around the clock every day of the year to report cardiopulmonary symptoms and serious complaints. Training sessions on nutrition, movement and pharmacotherapy complete the programme and reinforce the patient's self-reliance in dealing with himself and his illness.

After hospitalisation or after the conclusion of the individual titration phase during the initiation of drug therapy, which generally lasts about 6 months, there is a de-escalation of the device-based home monitoring, as part

Table 1: Selected telemedical support projects for patients with chronic heart failure in Germany.

Project	HeiTel-Telemedicine	CorBene	Telemedicine for the Heart	Telemed Brandenburg	Partnership for the Heart	HerzAs	Pro Heart/ Herzensgut
Partner	200 GP and specialists	Cardiologists, GP hospitals, Rehabilitation facilities, Medtronic GmbH	German Foundation for the Chronically III	Cardiologists, GP, local and regional hospitals, Deutsches Herz-zentrum Berlin	Bosch Telemedicine GmbH, Intercomponent Ware AG, getemed AG, T-Mobile GmbH	BNK Westfalen-Lippe	BNK Service GmbH, KKH Allianz
Associate partners	AOK Baden-Württemberg	Study groups of the Betriebs-Krankenkassen NRW/Saarland	Techniker Kranke kasse	AOK Branden-burg	Barmer Ersatz-kasse	AOK Westfalen-Lippe, KVWL-Consult	
Telemedical provider	SHL Telemedicine Düsseldorf	Vitaphone GmbH Mannheim	Vitaphone GmbH Mannheim	TMZ Brandenburg, getemed Teltow	Telemedical center Charite Berlin, Telemedical center Robert-Bosch-Hospital Stuttgart	Institute for applied telemedicine Bad Oeynhausen	Almeda AG München
Start of the project	2006.09.01	2005.12.01	2006.01.01	2004	2005.01.01	2008.01.01	2004.01.01
End of the project	2010.12.31	unlimited	unlimited	unlimited	2010.06.30	unlimited	until 12/2009
Number of patients	217	2928	1100	300	710	420*	1545
NYHA stage I	48	530	0	0	0	11	456
NYHA stage II	83	2062	627	0	312	116	488
NYHA stage III	85	302	429	195	398	174	317
NYHA stage IV	1	34	44	105	0	6	284
Duration	12 months	unlimited	6–27 months	at least 1 year	25 months	at least 1 years	2 years

Table 1: Continued.

Project	HeiTel-Telemedicine	CorBene	Telemedicine for the Heart	Telemed Brandenburg	Partnership for the Heart	HerzAs	Pro Heart/ Herzensgut
Transmitted parameters	Body weight, ECG/heart rate, blood pressure	Body weight, ECG/heart rate, symptoms	Body weight, heart rate, blood pressure	Body weight, ECG/heart rate, blood pressure, thorax impedance and breathing rate, oxygen saturation, symptoms	Body weight, ECG/heart rate, blood pressure physical activity, Self perceptance	Body weight, ECG/heart rate, blood pressure	Body weight, heart rate, blood pressure
Modular system for telemedical monitoring	yes	yes	yes	limited	yes	yes	no
Compliance management	yes	yes	yes	yes	yes	yes	yes
Patient education program	yes	yes	yes	yes	yes	yes	yes
Emergency management	yes	yes (24/7)	limited	yes	yes (24/7)	yes	limited
Medical scientific assessment	yes	yes	yes	yes	yes	yes	no
Health-economic assessment	yes	yes	yes	yes	yes	yes	yes
Further informations	http://www.klinikum.uni-heidelberg.de/	http://www.vitaphone.de/	http://www.dsck.de/	http://www.tmzb.com/	http://www.partnership-for-the-heart.de/	http://www.hdz-nrw.de/	http://www.almeda.com/

(*in 113 patients the NYHA stage was not determined).

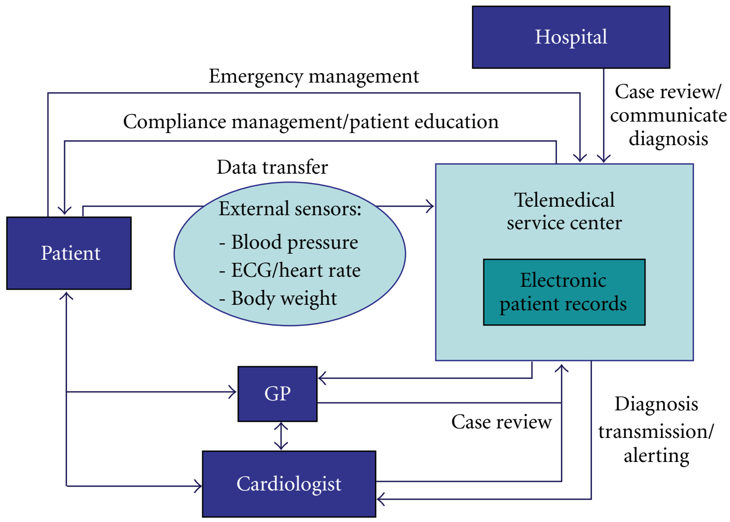

FIGURE 1: Overview of a complex telemedical support system for patients with chronic heart failure.

of a modular plan, which then becomes care provision by means of training sessions on nutrition, movement and monitoring of pharmacotherapy using a nurse call system. The purpose of this is to reinforce the patient's self-reliance in coping with himself and his illness and to perpetuate the success of treatment.

This modular plan offers the opportunity of establishing telemedical care as a cost-efficient module that is integrated into a chain of medical services. More than 200 general practitioners and cardiologists are currently actively participating in this plan.

The accompanying evaluation of the project documented a high-level of satisfaction among the participants. It moreover, also demonstrated the plan's efficiency in terms of health economics by means of a significant reduction both in the overall costs and in the number of days of hospitalisation for the HeiTel patients ($n = 210$) in comparison to a control group ($n = 12\,000$) over a period of 2 years. This justifies the assumption that the intervention has a lasting effect. Although the plan was only designed for 12 months, these results led to an extension of the contract for integrated care.

2.2. The Telemedicine Centre Brandenburg (TMZB). The Telemedicine Centre Brandenburg (Telemedizin Zentrum Brandenburg, tmzb) was established in 2004 by the Municipal Hospital Brandenburg in Brandenburg/Havel. Its aim is to improve the care for chronic cardiac patients in the federal state of Brandenburg. In cooperation with getemed, a medical technology company, and with funding by the European Union and by the Ministry of Economics of the state of Brandenburg a telemonitoring unit was developed which daily records and transmits all noninvasively parameters and information regarding clinical symptoms, drug compliance, and desired contact.

The promising results of a self-financed pilot study led to a contract with the AOK Brandenburg (a state-licensed health insurance company) for integrated medical care for patients with chronic heart failure.

Cooperations with various hospitals were established, including the German Heart Centre in Berlin, and numerous hospitals in the state of Brandenburg, as well as consulting cardiologists and general practitioners. The telemedical monitoring allows surveillance of patients from far distance, which is advantageous in a large, sparsely populated state with a low density of physicians.

Inclusion criteria are chronic heart failure NYHA stages III-IV, an ejection fraction ≤40%, and a history of hospitalization for acute decompensated heart failure. At the moment, 300 patients of NYHA stages III and IV participate in the program.

The patients receive a telemonitoring device, developed by getemed, Teltow, a scale, ECG electrodes, and a blood pressure gauge. The patient daily measures weight, blood pressure, ECG, thorax impedance and breathing rate, and for certain indications also oxygen saturation. Patients also provide information regarding the severity of dyspnea, their subjective well-being, medication intake, and preference regarding desired personal contact. The data is encoded and transmitted by internet to the TMBZ, where it is analysed weekdays with regard to newly manifested arrhythmias, heart rate, body weight, and blood pressure using individually determined threshold values, breathing rate, and, if indicated, the oxygen saturation. The patient's subjective comments regarding dyspnea, peripheral edema, well-being, and drug compliance are evaluated to detect worsening symptoms.

If deterioration has been detected, the patient's physician is informed by fax or, in urgent cases, via telephone by the tmzb. A summary of the reported results is included. This objective data enables better adjustment of the patient's medication according to individually changing health status.

The patient is contacted by the tmzb if: (i) suspicious changes of parameters are recorded, (ii) the patient requested contact, (iii) no data was transmitted, or (iv) the preceding intervention was not successful.

The closer collaboration between the individual patients and their individual care givers (patient, general practitioner, cardiologist, hospital, telemedical centre) allows for an optimal care. The acceptance of telemonitoring among patients is very high, as indicated by the fact that the compliance with data transfer is 95%. Patients indicate that they feel secure. No serious technical problems have been encountered. Preliminary analyses of the data show a significant reduction both in number and days of hospitalisations for acutely decompensated heart failure [23].

2.3. "CorBene". The "CorBene" project was developed as a contract for providing integrated care between practicing cardiologists, the Ford and Rhineland company health insurance programme, and the companies Vitaphone (Mannheim) and Medtronic (Düsseldorf). The goal is a transsectoral, stage-specific therapy of patients with chronic heart failure that is based on telemonitoring and is conducted according to guidelines. The participating doctors profit from a uniform documentation, improved exchange of information, and integrated quality management. This prevents, for example, redundant examinations. The telemedical concept of monitoring consists of four modules. This guarantees that the telemonitoring is appropriate to the NYHA stage and is individual. In module 1, the patient is given an ECG monitoring card to record his heart frequency and detect cardiac arrhythmias. Module 2 consists of weight monitoring. ECG and weight monitoring are linked together in modules 3 and 4. All reported data is integrated into an electronic patient record by the telemedical service centre Vitaphone, which is certified according to ISO and the Association for Engineering/Electronics/Information Technology (VDE) rules of application for telemonitoring [23, 24]. In addition, the staff of the telemedical service centre contacts the patient by telephone regularly, on a daily basis if needed. They enquire about symptoms that suggest imminent cardiac decompensation. There is also a reminder function for taking medication. Emergency management, including alerting the rescue services, is provided, made possible by the round-the-clock presence of physicians at the telemedical centre.

The "CorBene" project is being evaluated in terms of health economics. Initial data from 306 patients show that 81.2% of the patients included in the project are being treated according to the guidelines. 10.8% of these patients show clear improvement of clinical symptoms since they have been included in the project [25]. The final results of the health economics evaluation of the project are not yet available.

In the meantime, "CorBene", which initially was a regional project, has been extended to cover all of North Rhine Westphalia (NRW) and Saarland. Currently more than 2900 patients with chronic heart failure are monitored by the project.

2.4. "Telemedicine for the Heart". Integrated concepts of providing medical care that utilize telemedicine have been proven to be appropriate instruments for improving current deficits for patients with cardiac failure. For this reason the Techniker Krankenkasse health insurance company and the German Foundation for the Chronically Ill developed the integrated programme of medical care called "Telemedicine for the Heart". Patients from throughout Germany with NYHA stages II-IV who are insured with the Techniker Krankenkasse have profited from this programme since January 1st, 2006.

The modularly structured programme for providing care, collecting data, interpreting data and training patients allows the participants to deal with their illness in a safer more self-empowered manner. It is also an important adjuvant to the treatment provided by their physicians. The goal of the patient-centred programme is to help the participating patients gain patient empowerment, to understand their illness better, to make the influencing factors between chronic heart failure, the prescribed medicine and their own life style more transparent. It also increases patient awareness of warning signs and symptoms, that indicate imminent decompensation. The analysis of life style with reference to the patient's own health situation encourages participants to reduce risk factors and expand health-promoting factors. By means of close coordination with the locally responsible physician, the programme aims to reduce the frequency and length of inpatient hospitalisations, at decreasing mortality, and at offering participants coordinated and high-quality medical care [26].

The programme is set to run for 27 months, which are divided into three phases. The first 6-month is the training phase. It familiarises the patients with the procedures of the programme and, by means of telephone-based training, provides specific knowledge about the complex topics associated with chronic heart failure. The second phase is the 3-month stabilisation phase. It promotes a consolidation of the behavioural patterns taught during the first phase and attempts to teach how to deal with the illness independently on a daily basis. The third phase consists of an 18-month refresher phase, aiming to anchor the behavioural patterns that promote better health in daily routines of participating patients, through constant repetition. This should allow, the results that have been achieved to be maintained after the participants have left the programme. The care and training given to patients is provided by a telemedical service centre (in this programme, Vitaphone). An electronic record is maintained for each patient at the telemedical service centre. For patients in NYHA stages III and IV, telemedical monitoring of body weight, blood pressure, and the pulse is also planned. During the programme, necessary interventions are made by the telemedical service centre team in coordination with the general practitioners and/or the cardiologists if a threshold is crossed.

In the context of a health economics evaluation conducted by the chair of health management at the University of Erlangen-Nuremberg, the data of 281 participants in the programme "Telemedicine for the Heart" (treatment group) were compared to the data of a matched control group that was three times larger in size. Examination of the number of hospitalisations per patient and year, showed that for the participants in the programme there were 21.5% fewer hospitalisations ($P = .03$, t-test). This means that it was possible to avoid approximately every fifth hospitalisation as the result of this intervention (i) an improved level of knowledge among the participating patients, (ii) an early warning function of the telemedical monitoring, and (iii) close coordination between the telemedical centre and the responsible physicians.

The evaluation also provides a clearly positive result with regard to mortality. In the group of programme participants, there was a 51.7% ($P = .01$, chi-squared test) reduction in mortality within the first year, that is, that with the most intensive training and support phases. Even if the analysis is extended to the maximum period of time (including the last phase of the programme with a low intensity of care provision), the mortality was reduced by 35.1% ($P = .04$, chi-squared test), a value more than one third lower than the mortality in the comparison group.

In the context of the evaluation, it could be shown that the programme participants had a uniformly higher supply rate of heart-specific medication. The training sessions focused on heart failure and the communication optimised within the integrated care context met the programme's goal of promoting the prescription of diagnosis and guideline specific drugs.

The medical effects reported above were achieved in a cost-efficient manner, as is shown by the overall costs. There are substantial differences in favour of the treatment group, both after 1 year of programme membership (savings of 1592.16€, 18.1% of the total costs) as well as over the maximum period of time observed normalised per year (savings of 2633.40€, 25.0% of the total costs). These data make it clear that the complete 27-month programme fully paid for itself in its first year of work, while the effects of the care provision—especially the effect of the training sessions—were maintained over a much longer period of time.

In summary, the evaluation showed that the optimised interplay of therapeutic supervision by the local physician with the supportive care and training sessions provided by "Telemedicine for the Heart" offers an important contribution to stabilising patients' health status. This programme is able to train the participants in a cost-efficient manner. They learn to deal with their illness and to recognise imminent decompensation early, especially if using specific telemedical technology and the close coordination with their physicians. This allows for the adjustment of therapy even on an outpatient basis, lowering mortality, and avoiding repeated and cost-intensive hospitalisations.

2.5. "Partnership for the Heart". The research and development project "Partnership for the Heart" is jointly sponsored by the Charité, University of Medicine Berlin, the Robert Bosch Hospital in Stuttgart, and three industrial partners. This project receives support from the government agency for economics and technology.

The aim of the project is to establish a sensor platform for patients, an electronic record for patients, as well as a telemedical centre [27]. The sensor platform is a wireless network (local area network) in the patient's home. Various sensors (for measuring blood pressure, a three-channel ECG, weighing scales, and an activity sensor) are integrated into this network. The sensors are connected wirelessly via Bluetooth to a PDA that is part of a mobile phone network. The measured data is ultimately transferred to the telemedical center via the PDA. At the telemedical center, the data is integrated into the patient's electronic record. The telemedical centres are directly attached to the hospitals (Charité Berlin, and Robert Bosch Hospital in Stuttgart) and are staffed by physicians and caregivers. The staff also has the contact data of the patients' general practitioners and specialists and the phone numbers of the regional emergency services [27].

The Partnership for the Heart study has examined a total of 710 patients since January 2008. It is a multicentric randomised prospective study of patients with chronic heart failure that uses an open and controlled design (telemedical participants and a control group) and follows patients for a period of at least 12 months. In the telemedical group, there is daily monitoring of blood pressure, ECG, oxygen saturation, and body weight. Furthermore the patients' physical activity is evaluated by an activity sensor and the patient himself evaluates his own health status. The study is financed and supported logistically by the Barmer and Bosch health insurance companies. The primary end point of the study is the period of survival. Secondary end points of the study are overall mortality, cardiovascular mortality, frequency of any kind of nonelective hospitalisation, frequency of hospitalisations for cardiovascular reasons, the plasma level of NT-proBNP over time and the quality of life over time, An evaluation from the perspective of health economics is planned [27, 28].

2.6. "HeartAs/HerzAs". The project "HeartAs" was established in combination with an integrated-care contract. Until now, 516 patients have been included in the project, 96 of which have already concluded the program. The majority of patients are in NYHA stage II and III. In this project, body weight, ECG (12-channel or 1-channel), pulse, and blood pressure are transmitted. The project consists of a modular character. In addition to compliance management and emergency management modules, regular telephoneadvice calls are given. A medical, academic, and economic (cost benefit analysis) evaluation will follow.

2.7. "ProHeart/Herzensgut". Some initial experience regarding the telemedical monitoring of patients with chronic heart failure has been gathered in a project organised by the health insurance company "Kaufmännische Krankenkasse" and the Almeda company in Munich. The idea behind this project was similar to that of the ProHeart project. Participants were contacted regularly by telephone by specially trained medical personnel. On the one hand, the use of specially developed software meant that the telephone conversations were very standardized, while on the other, there was always an opportunity to discuss the patient's situation in detail in an individual and problem-oriented manner. The telephone contacts were supplemented by written training material [29]. There was, in addition, telemetric monitoring of the patient's weight. Compared to a control group with 183 patients, it was possible to lower the number of days in hospital by 48% in the group of participants (214 patients). An overall reduction in cost of 39.5% was achieved. The evaluation was conducted in a stratified manner over a 1-year period, while the observation period was in fact at least 6 months and at most 18 [30].

During the observation period, 14.7% of the participating patients died, compared to 27.1% in the control group. This difference was statistically significant [30].

The project "ProHeart" is currently conducted by Almeda company and the Allianz health insurance. Up to now, 1545 patients in NYHA stages I–IV have been included in the project

3. Discussion

The German projects on telemedical monitoring of patients with chronic heart failure that are described individually above exhibit different approaches and plans for improving the situation of these patients. Nonetheless, they share some fundamental strategies. The goals are, besides monitoring the patients' status (weight, blood pressure, ECG), to remind patients of their medication, to monitor symptoms indicative of imminent cardiac decompensation, and to train patients on topics relevant to heart failure. A significant concern of all the programmes is increasing the ability of the patients themselves to manage their own illness. Most programmes are planned for a limited time period. The timely limitations of this program have to be discussed critically. Most of the projects described were established and conducted within the confines of integrated-care-contracts over a predefined frame of time. Undisputed is the fact that chronic heart failure can improve only with consistent surveillance, for which reason patients need further long-term monitoring. This poses the question of which patients (NYHA stage) derive the most benefit from telemonitoring and which intensity (daily, weekly…monitoring) should be adjusted to individual patient needs. As a foundation, consistent definition and measures of goals needs to be defined (mortality, rehospitalisation, quality-of-life). The discussed projects demonstrate the heterogeneous of patients included according to differences in NYHA stages.

In a meta-analysis of 14 randomised controlled studies on telemonitoring of patients with heart failure, Clark et al. demonstrated there was a 20% reduction in overall mortality [17]. The effect was greater in the telemonitoring programmes than in the structured telephone. It is essential to distinguish between the structured telephone support and the telemonitoring programmes with transfer of vital parameters (body weight, heart frequency, blood pressure, ECG) [17].The effects were greater in the telemonitoring programmes than in the structured telephone support programmes, although the difference was not statistically significant. Furthermore, the rate of rehospitalisation for cardiac decompensation was reduced by 21%. Here, too, there was no difference between the two groups [17].

Roth [31] and associates could demonstrate a reduction of total hospital days of 66% with the usage of telemonitoring in patients with chronic heart failure, in the SHL Telemedicine Projects. Most patients reported a significant improvement of their quality-of-life [31].

The results clearly show that telemonitoring and telephone support programmes are beneficial with regard to mortality and the rehospitalisation rates for patients with chronic heart failure [15–17]. The central question continues to be the nature of the intervention that the patient requires. The results of the TEN-HMS study show that the results for mortality and rehospitalisation were similar in both groups. The programmes in the device-based telemedicine branch, however, were more cost efficient than the other programmes even after the system-related additional costs for the devices were included, since it was possible to shorten the length of in-patient treatment [18]. This makes a differentiated use of telemedicine necessary for individual patients. The range of items to be monitored should be selected according to NYHA stage and be modular. For most patients in NYHA stage II, a telephone support programme with monitoring of symptoms, compliance management, training, and facilitating self-observation appears to be sufficient in most cases. Patients in NYHA stages III and IV would benefit more from telemonitoring with the additional daily transfer of vital parameters. The telemedical monitoring software should also have an individual character. In practice, this means that only those parameters relevant for the individual patient (e.g., body weight, blood pressure) are monitored. At the patient's end, these parameters are transmitted, for instance, using Bluetooth via the individual devices (such as weighing scales, blood pressure gauge) to a central patient monitor. The patient monitor transmits the data on to the telemedical service centre, generally via landline. Currently, it depends on the telemedical provider involved which of the different hardware components are available. The systems are not compatible with each other. This means that a modular structure of heart failure programmes that accords with the NYHA stages is an indicator of quality in such programmes. In Table 2, the quality requirements on telemedical monitoring programmes for patients with chronic heart failure are summarized. In two current randomised studies on telemonitoring [Home or Hospital in Heart Failure (HHH) Study and Home Heart Failure (HF) Study] could show evidence of a high degree of compliance in data transmission even in older patients [32, 33]. However, the use of telemedical monitoring in the HHH Study was unable to significantly reduce the duration of in-patient treatment for cardiac failure, cardiac death and hospitalisation due to heart failure in comparison to usual treatment. Similar results were reported in the Home HF Study [33].

The reasons discussed for this include the high level of standard treatment for heart failure and intermittent data transmission (once a week) [32]. The telemedical projects conducted in Germany monitor a variety of vital parameters (e.g., weight monitoring only or complex monitoring of weight, ECG, blood pressure, pulsoximetry) and define various monitoring intervals (daily or weekly). In order to be able to compare the results, standardisation seems necessary (choice of vital parameters to monitor, transmission intervals, automatic data transmission; Table 2).

Table 2: Quality requirements for telemedical support programmes for patients with chronic heart failure.

(i) Monitoring according to the NYHA stage
(ii) Ensuring treatment according to guidelines
(iii) Creating a modular system for individual telemedical monitoring
(iv) Standardizing telemedical monitoring (selection of vital parameters, transmission intervals, automatic data transfer)
(v) Integrating the recorded data in an electronic patient record
(vi) Networking between partners (general practitioner, cardiologist in private practice, hospital, rehabilitation facility)
(vii) Certification of the telemedical service centre according to defined standards
(viii) Establishing standardised operating procedures (SOPs) in telemedical service centres
(ix) Establishing an emergency management plan
(x) Contacting the patient directly by phone for reviewing symptoms, medication adherence, consultation
(xi) Enabling the patient to be self-reliant
(xii) Accompanying patient education with structured training programmes
(xiii) Accompanying medical and health-economic assessment

The electronic patient record is the central component of telemedical patient monitoring. Recognising deviations from established alarm thresholds allows both patients and the treating physician (general practitioners, cardiologists) to be alerted promptly. This permits close coordination between the partners and early intervention in the patient. In addition, personal telephone contact to the patient is established through the telemedical service centre. By means of this, enquiries can be made about symptoms and complaints, it can be checked whether medication is being taken, and patient education can be coordinated. The quality of the telemedical care systems depends significantly on the work of the employees in the telemedical service centre. The aim here must be to standardise procedures and certification of the telemedical service centres in the context of quality assurance (Table 2). To this end, uniform standardized operating procedures (SOPs) must be defined and put into practice. In Germany, telemedical support is provided by specialized telemedical service centres. These may be associated with individual Hospitals or be commercial providers (i.e., SHL Telemedicine, Vitaphone, or Almeda). In these telemedical service centers, specially trained personnel contacts patients and physicians, monitors the vital signs, and maintains the electronic patient record. The association for Engineering/Electronics/Information Technology e.V. (VDE) has established guidelines for telemonitoring and certifies telemedical service centers [24, 34]. This is the first step toward standardization and comparability of different programs.

Another essential concern in telemedical monitoring is intercommunication between general practitioners, cardiologists in private practice, hospitals and rehabilitation facilities. This aspect is of great importance in Germany since here there is traditionally a great division between outpatient and inpatient sectors. Most telemedical monitoring programmes were conducted for this reason in the context of contracts for integrated care. In doing this, in addition to physicians, medical insurance companies and telemedical providers would be directly included in the projects.

The greatest challenge at the moment is the reimbursement of telemedical services. This applies both to the service providers (physicians in private practice, hospitals) and the telemedical providers. At the moment in Germany, telemedicine for monitoring patients with chronic heart failure is not a component of standard treatment. Thus it can also be explained why most projects are regional in character. In the next few years, it will be necessary to more strongly develop the evidence of the benefits of telemedical monitoring in patients with heart failure. For this, in addition to medical and economic evaluations (mortality, rehospitalisation rates, therapy according to guidelines, quality of life), health-economic evaluations are also necessary. The programmes presented here have this health-economic evaluation integrated into them as a fixed component of the programmes. Proof of the cost efficiency of the programmes will be a crucial point for the future of telemedical monitoring programmes. Currently, none of the described projects have been completed, so that final results are not yet available.

4. Summary and Perspective

In Germany, various projects on telemedical monitoring of patients with chronic heart failure could have been set up in the past few years. Most of these projects were initiated in the context of contracts of integrated care and are mostly regional in nature. The telemedical monitoring programmes differ in terms of their choice of monitored vital parameters, sequence and frequency of data transmission, and duration. This makes a comparison only possible to a limited extent. In addition, most of the programmes are not yet completed, so that no final assessment of the medical-economic or health-economic evaluation is yet possible. The further acceptance of patients and sponsors of projects on telemedical monitoring of patients with chronic heart failure will depend in the future on the evidence for improvement of the medical variables (mortality, hospitalisation rate, duration of hospital treatment) as well as evidence of cost efficiency. Standardization is required of the programmes for telemedical monitoring of patients with chronic heart failure according to defined quality criteria.

For the context of further studies some basic questions, such as which patients (NYHA stage) derive the most benefit at which degree of intensity of telemonitoring, need to be considered, in order to achieve lasting improvements for these patients. In addition, attention need to be given to the affects of the physical separation of telemonitoring on the doctor-patient relationship in order to increase the physician's and patient's acceptance of telemonitoring.

Conflict of Interests

The authors declare that no conflict of interests exists.

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 137201, 17 pages
doi:10.1155/2010/137201

Research Article

e-SCP-ECG$^+$ Protocol: An Expansion on SCP-ECG Protocol for Health Telemonitoring—Pilot Implementation

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Received 30 October 2009; Accepted 23 March 2010

Academic Editor: George Anastasopoulos

Standard Communication Protocol for Computer-assisted Electrocardiography (SCP-ECG) provides standardized communication among different ECG devices and medical information systems. This paper extends the use of this protocol in order to be included in health monitoring systems. It introduces new sections into SCP-ECG structure for transferring data for positioning, allergies, and five additional biosignals: noninvasive blood pressure (NiBP), body temperature (Temp), Carbon dioxide (CO_2), blood oxygen saturation (SPO_2), and pulse rate. It also introduces new tags in existing sections for transferring comprehensive demographic data. The proposed enhanced version is referred to as e-SCP-ECG$^+$ protocol. This paper also considers the pilot implementation of the new protocol as a software component in a Health Telemonitoring System.

1. Introduction

Nowadays, the health management of the elderly and less able or those with chronic health problems tends to guarantee their quality of life. It is suggested that there should be continuous monitoring of their daily activities and the evaluation of their vital operations and the context parameters that affect them. The long-term monitoring of such factors should indicate all changes or trends in an individuals' health status and influence the response and management of their diseases [1]. Hence, for example, a patient's living and working conditions in correlation with possible allergies may aggravate his health or considerably affect his medication.

Current efforts for the accomplishment of this objective tend towards the creation of ubiquitous Health Telemonitoring Systems (HTSs) that enable remote observation of an individual and decision-making in case of a health crisis (e.g., with the intervention of health experts). The HTSs allow these persons to move and act without constraints, according to their abilities. They may also be applied efficiently for persons with different profiles, for example, epileptic, diabetic, asthmatic, and phobic.

Hence, the HTSs should be based upon open and flexible architectures allowing the integration of various vital and context information. From the architectural point of view, they usually include two core entities. The first is a Body Area Network (BAN) acquiring biosignal information, such as Electrocardiogram (ECG), noninvasive blood pressure (NiBP), body temperature (Temp), and pulses. The second entity acquires context awareness, positioning and environment information, such as humidity and temperature [2].

The integration of the whole acquired vital and context data into the structure of a single file or message is critical for the efficient operation of the HTSs within client-server or peer-to-peer (P2P) applications [3–5]. In this way, both the total transactions of the final user and uncertainty in the affirmation of an accurate correct decision are minimized.

Note that some standards organizations have already defined file formats and protocols integrating different types of medical information. They usually include trivial patient elements, such as code, name, surname, weight, and height.

These structures integrate primarily ECG and electroencephalogram (EEG) biosignals and secondarily the NiBP, Temp, blood Oxygen Saturation (SPO_2), Carbon dioxide (CO_2), pulse rate, and so forth. For example, the SCP-ECG integrates ECG, TEMP, and NiBP, the EDF+ integrates EEG, ECG, and CO_2, while the CEN File Exchange Format is the only structure that integrates more biosignal types. The characteristics and the performance of these protocols are extensively analyzed in [6–8].

It is obvious that none of these protocols is able to support by itself the full functionality of the HTSs. Two or more protocols should be used concurrently, thus introducing a high degree of complexity.

The main aim of this work is to analyze the capabilities of the existing medical data protocols and to propose respective expansions for them, in order to support the full functionality of the HTSs. This analysis has led us to propose an extension of the SCP-ECG protocol; the expanded protocol is thereafter referred as e-SCP-ECG$^+$ protocol.

The structure of e-SCP-ECG$^+$ protocol includes sections for vital, context aware, and patient-centric data. The sections for vital signs comprise at least six biosignals (ECG, NiBP, SPO_2, Temp, CO_2, and Pulse Rate) as well as plethysmographic (PLE) data for SPO_2. The context aware section comprises at the very least the geolocation data and altitude. The patient-centric information section incorporates data about allergies, blood group, environmental elements (residence, work, etc.), and personal constraints (e.g., interdiction of blood-transfusion for religious reasons).

This paper also demonstrates the pilot implementation of an HTS that makes use of the e-SCP-ECG$^+$ protocol. Earlier versions of the e-SCP-ECG$^+$ protocol have been already tested in telemedicine projects [4, 5].

Section 2 presents the state of the art in existing medical standards and also the reason we choose to extend the SCP-ECG protocol. Section 3 presents the extensions included in the e-SCP-ECG$^+$ protocol. Section 4 presents the implementation of a pilot HTS using the e-SCP-ECG$^+$ protocol. In Section 5 the authors discuss the advantages of the e-SCP-ECG$^+$ protocol and the pilot real world operation of the implemented HTS used to evaluate the new protocol. Finally, a conclusion is reached in Section 6.

2. Existing Medical Data Standards in Health Monitoring

2.1. State of the Art in Existing Medical Data Standards. This chapter analyses the characteristics of the existing standards employed for the organization, management, and distribution of biosignals and other medical information.

SCP-ECG (CEN/ENC 1064 Standard Communication Protocol for computer assisted Electrocardiography) [9, 10] is a standard data format established by the European Standard Committee (CEN) for ECG recordings. It defines the patient's ECG data structure, the basic demographics format, and also rules for data interchange between digital ECGs and computer systems. It can handle binary signals and annotations in a number of defined sections as they are obtained in different tests with ECG recordings. These tests include short-term and long-term ECG recordings, stress tests with ECG, and also angiography with ECG. In addition, it can handle data compression using known algorithms. It is a recommendable alternative to ECG databases.

DICOM (Digital Imaging Communication in Medicine) supplement 30 [11] covers the waveform acquisition within the imaging context. It is specifically meant to address waveform acquisitions to be analyzed with other data transferred and managed using the DICOM protocol. It allows the addition of waveform data to that context with minimal incremental cost. Further, it leverages the DICOM persistent object capability for maintaining referential relationships to other data collected in a multimodality environment, including references necessary for multimodality synchronization.

HL7 (Health level 7) is an international organization developing healthcare standards for clinical and administrative data. The HL7-annotated ECG (HL7 aECG) [12] was developed by the HL7-Regulated Clinical Research Information Management Technical Committee using the draft-annotated ECG nomenclature developed by IEEE 1073.

ISHENE Standard Output Format for Digital Holter Data [13] is a single file structurally organized in a header followed by a (larger) data block containing all stored ECG digital samples.

EDF (European Data Format) [14] is a simple and flexible format for exchange and storage of multichannel biological and physical signals. The signals can have any physical dimensions and sampling frequencies. The EDF file has an ASCII header containing mainly patient and time identification, the number of signals, and the technical characteristics such as the main dimension, calibration values, and sampling frequency of each signal. The header is followed by subsequent data records. The duration of the data records is specified in the ASCII header. The EDF+ file can also contain interrupted recordings, annotations, stimuli, and events.

CEN/FEF (File Exchange Format for Vital Signs) [15] incorporates data items coming mainly from intensive care units, anaesthesia departments, and clinical laboratories including neurology. The FEF biosignal files consist of sections. Each section begins with a tag for section identification purposes, followed by a length field indicating the length of the section and the actual data. The demographics section contains information about the recorded patient, whereas the healthcare provider section stores basic textual data of the healthcare institution and personnel that collected the data. A section concerning the medical device system presentation contains a structured description of the devices (one or many) that participated in the data collection. There is also an optional manufacturer-specific section. The FEF definition process is a serious attempt to unify biosignal and related measurement offline storage needs for both the various electrophysiological laboratories and intensive care/anaesthesia departments.

IEEE 1073 is a comprehensive standard for electronic signal data communication between medical devices and bedside monitoring devices [16]. It is designed specifically

Table 1: SCP-ECG protocol Data Structure.

Section	Type	Information Description
0	Required	Pointers to data areas in the record
1	Required	Header Information—Patient data/ECG acquisition data
2	Dependent	Huffman tables used in encoding of ECG data (if used)
3	Required	ECG lead definition
4	Optional	QRS locations (if reference beats are encoded)
5	Optional	Encoded reference beat data if reference beats are stored
6	Required	"Residual signal" after reference beat subtraction if reference beats are stored, or encoded rhythm data
7	Optional	Global measurements
8	Optional	Textual diagnosis from the "interpretive" device
9	Optional	Manufacturer specific diagnostic and over reading data from the "interpretive" device
10	Optional	Lead measurements results
11	Optional	Universal statement codes resulting from the interpretation

for acute care, with requirements such as the ability to handle frequent network reconfiguration, the plug and play operation, the robust and reliable communications for a safety critical application, and the association between a device and a specific patient [17]. This protocol is specialized at the medical device level, and it is not always easy to apply.

MFER (Medical waveform description Format Encoding Rule) [18] is a standard developed by the Japanese standard organization, specialized for waveforms such as ECG and EEG. It is only specialized in medical waveforms. For encoding information other than medical waveforms, it recommends the usage of another format such as the HL7, DICOM, or IEEE 1073.

ASTM 1467 [19] is the only standard for neurophysiology supported by the American standard body. It offers support for EEGs, polysomnograms (PSGs), evoked potentials (EPs), electromyograms (EMGs), and so forth. It is also suitable for ECGs.

EBS (Extensible Biosignal Format) [20] is a simple binary file format for storing multichannel time-series recordings and associated metadata. It was used primarily for handling EEG, MEG, and ECoG recordings from human brains. It can also handle the patient's or subject's name, identifier, date of birth, sex, and various other data relative to the acquisition process.

2.2. Why We Adopt the Solution of Extending SCP-ECG Protocol. During the investigation period of the above protocols in order to find a protocol that meets our needs and also is easily expandable and independent from "parent" protocols (e.g., DICOM and supplement 30), we studied and analyzed the aforementioned protocols and also some corresponding papers like [6–8]. The analysis has demonstrated that two of these are closer to our needs, the CEN/FEF and the SCP-ECG. The CEN/FEF protocol, although covering a wide area of biosignals, has increased complexity of implementation. This protocol, moreover, has rare implementations [6]. On the other hand, the SCP-ECG protocol is well defined and structured, provides the widest expansion capabilities, and is supported by many major manufacturers of ECG equipment [6]. More precisely, it incorporates a patient's ECG data structure, an elementary demographics format, and rules for interchanging data between digital ECG carts and hosts that, respectively, acquire and store the ECG data.

All this information is included in an SCP-ECG formatted file that provides twelve (12) sections dedicated per information category (Table 1). Despite the protocol being designed to handle data on ECG measurements, these sections handle a significant amount of information. This file handles the minimum set of patient demographic data, a pair of values for the NiBP (low and high), and a value for heart pulse rate. It has also the capability to handle ECG data acquired using a different sampling rate, limited to a few minutes. Finally, it includes several sections for the handling of manufacturer-specific content that can adequately handle various types of information through continuous health monitoring applications.

3. The Proposed e-SCP-ECG$^+$ Protocol

The e-SCP-ECG$^+$ [21] protocol extends the SCP-ECG protocol in order to handle more information about patients and their vital signs than those asked by doctors during various telemedicine projects in the past.

So, the e-SCP-ECG$^+$ [21] protocol extends the existing Section-1 of the SCP-ECG with new tags for extra demographic related data and data reference to the equipment. Moreover, it extends the file structure of the SCP-ECG defining new sections (Section-200 to Section-207) for handling additional data, such as extra biosignals data, and the allergies, which are required for patient's health monitoring.

3.1. New Tags in Section-1. Section-1 is designed to transmit patient demographic data, as well as technician, physician, and equipment identification data. Flexibility is achieved by organizing different information within different successive recorded header fields. All header fields have a similar structure that consists of three parts: a "tag" (one byte) that indicates the contents of the parameter field, a "length" (two bytes) containing the length of the field value, and a "value" (zero to 65 Kbytes) containing the actual parameter data.

The protocol supports 255 (0 to 254) different header field types. The first 36 types (tag 0 to 35) and the last one (tag 255) are already used by the SCP-ECG protocol (Table 2), and 55 field types (tags 200 to 254) are reserved for use by any individual manufacturer. In this work, we propose the use of 17 field types (tags 200 to 216) for the extra needs of the e-SCP-ECG$^+$ protocol.

Table 3 depicts the proposed specification of the newly defined parameters included within the field types with tags 200 to 216. These fields are defined as optional. In some cases, selected fields may be labelled as "unethical", and the patient's agreement is critical in order for them to be filled in. For example, the "patient religion" field should be filled in only special cases, in order to indicate nonmedical restrictions affecting the applied medical treatment, for example, blood transfusion that is prohibited in some religions.

3.2. New Sections. The SCP-ECG protocol currently defines section ID numbers 0 through 11 in its structure, reserves section numbers 12 to 127, as well as numbers above 1023, for future use, and leaves numbers 128 through 1023 for manufacturer-specific sections. The e-SCP-ECG$^+$ protocol assigns and uses the following extra eight (8) new sections:

(i) Section-200 for SPO_2 and arterial pulse rate data,
(ii) Section-201 for Temp data,
(iii) Section-202 for CO_2 data,
(iv) Section-203 for NiBP data (systolic—diastolic) and Pulse Rate data,
(v) Section-204 for allergy information,
(vi) Section-205 for plethysmographic (PLE) data,
(vii) Section-206 as an extension of Section 6 for long-length/interrupted ECG data,
(viii) Section-207 for user's geolocation using Global Positioning System (GPS) data.

All the sections of the e-SCP-ECG$^+$ protocol adopt the general sections format of the SCP-ECG protocol constituted of two parts, the section Identification Header and the section Data Part [9]. The section Identification Header part is used without any modification. Below the structure of the Data Part (DP) of the eight (8) new sections is analyzed.

The *Section-200 DP* handles pairs of SPO_2 and Pulse Rate data samples acquired either using a permanent rhythm or asynchronously. It contains three parts (Figure 1). The "DP Header" keeps data on the sampling rate (time interval) and the number of data blocks collected. The "Data Parameters" determine parameters for each data block (date, time, and block length). The "Data Block" keeps successive recordings of the periodically acquired pairs of SPO_2—Pulse Rate values.

The *Section-201 DP* handles the Temp data samples acquired by using a permanent rhythm (measurement type (mt) equal to "1" (mt = 1)) or asynchronously (mt = 0). It consists of the "DP Header", which contains two parts ("mt" and "Units"), the "Data Parameters" and the "Data Block" (Figure 2). If mt = 1, "Data Parameters" records Date, Time, time interval, and number (#) of measurements. If mt = 0, "Data Parameters" record only the number (#) of measurements. The "Data Block" records the captured measurements.If mt = 1, "Data Block" keeps the successive recordings of the periodically acquired Temp values.

Table 2: Patient data/ECG acquisition data stored in Section-1.

tag	Contents
0	Last Name
1	First Name
2	Patient Identification Number
3	Second Last Name
10	Drugs
13	Diagnosis or Referral Indication
14	Acquiring Device Identification Number
15	Analyzing Device ID Number
16	Acquiring Institution Description
17	Analyzing Institution Description
18	Acquiring Department Description
19	Analyzing Department Description
20	Referring Physician
21	Latest Confirming Physician
22	Technician Description
23	Room Description
30	Free Text Field
31	ECG Sequence Number
35	Free-Text Medical History
255	

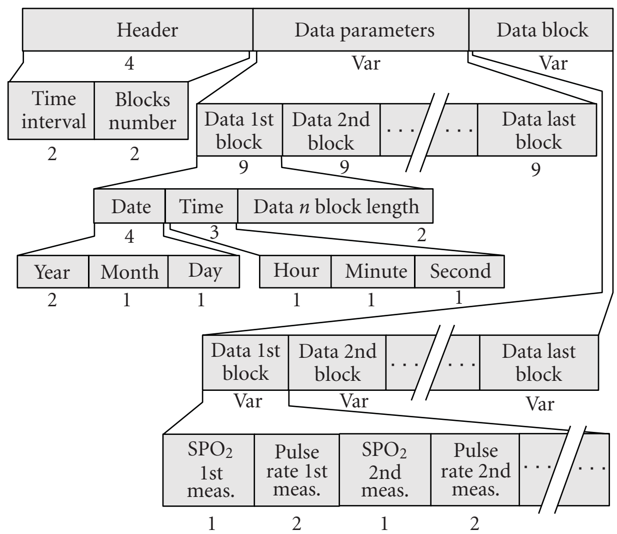

Figure 1: Overview of the data part holding the SPO_2 and pulse rate data (Section-200).

Table 3: New defined parameters stored in Section-1.

Tag	Length	Value (Parameter Data)		
200	length	Second patient ID (Text characters)		
201	2	Patient Nationality (Binary)		
		This has the following format:		
		Byte	*Contents*	
		1-2	binary: Nationality indication (ISO 3166.1) defined as:	
			0	Unspecified
			m^*	n^{**}
202	length	Patient Address (Text characters)		
203	length	Patient Phone Number (Text characters)		
204	1	Patient Religion (Binary)		
		This has the following format:		
		Byte	*Contents*	
		1	Binary: set equal to 255	
			0	Unspecified
			1	Atheist
			2	Baha'I
			3	Buddhism
			4	Christianity
			5	Confucianism
			6	Hinduism
			7	Islam
			8	Jainism
			9	Judaism
			10	Shinto
			11	Sikhism
			12	Daoism
			13	Zoroastrianism
			14–30	Reserved
			31–255	Manufacturer specific
205	length	Birth Place (Text characters)		
206	1	Patient Insurance (Binary)		
		This has the following format:		
		Byte	*Contents*	
		1-2	binary: Nationality indication (ISO 3166.1) defined as:	
			0	Unspecified
207	length	Memorial History (Free Text)		
		This field contains a text description of hereditary diseases.		
208	1	Blood Type (Binary)		
		This has the following format:		
		Byte	*Contents*	
		1	binary: set equal to 255	
			0	Unspecified
			1	A+
			2	A−
			3	B+
			4	B−
			5	AB+
			6	AB−
			7	O+
			8	O−

Table 3: Continued.

Tag	Length	Value (Parameter Data)		
209	length	Profession (Free Text)		
		This field contains a text description of people profession.		
210	1	File access (Binary)		
		This has the following format:		
		Byte	*Contents*	
		1	Binary: type of file access	
			0	read/write
			1	read only
			2	Locked
211	length	Access restrictions (Binary)		
		This has the following format:		
		Byte	*Contents*	
		1	Binary: type of access restrictions	
			0	All file contents available to all medical specialties
			1	File contents available depended to medical specialties
			2	All file contents available to specific medical specialty
		2	Binary: if byte 1 has value different from 0 then this field contains the medical specialty. There is no limit on the number of specialties.	
212	length	SPO_2 Machine ID Acquiring Device (Binary bytes and Text characters)		
213	length	NiBP Machine ID Acquiring Device (Binary bytes and Text characters)		
214	length	CO_2 Machine ID Acquiring Device (Binary bytes and Text characters)		
215	length	GPS Machine ID Device (Binary bytes and Text characters)		
216	1	Operational mode (Binary)		
		This has the following format:		
		Byte	*Contents*	
		1	0	Basic
			1	Emergency

* *m* the numeric values and ** *n* the description of the corresponding codes of countries in ISO 3166-1.

If mt = 0, "Data Block" keeps successive recordings of distinct Temp measurements (Date, Time and Temp value).

The *Section-202 DP* handles the CO_2 data. It contains two parts (Figure 3). The "DP Header" handles parameters of captured data (date, time, time interval, CO_2 units, and the number (#) of measurements). The "Data Block" keeps successive recordings of the periodically acquired CO_2 values.

The *Section-203 DP* handles triples of systolic-NiBP, diastolic-NiBP, and Pulse Rate data samples acquired either through a permanent rhythm (mt = 1) or asynchronously (mt = 0). It consists of the "DP Header", which contains the "mt", the "Data Parameters", and the "Data Block" (Figure 4). If mt = 1, "Data Parameters" records Date, Time, time interval, and number (#) of measurements. If mt = 0, "Data Parameters" record only the number (#) of measurements. The "Data Block" records the captured triples of measurements. If mt = 1, "Data Block" keeps the successive recordings of the periodically acquired values. If mt = 0, "Data Block" keeps successive recordings of distinct measurements (Date, Time, and values).

The *Section-204 DP* handles the data of five (5) allergies (rhinitis, asthma, medical allergy or drug allergy, food allergy, and other allergy). It has the same structure as Section-1, containing six (6) header fields, a header terminator, and a padding byte (Figure 5). Each header field concerns of a specific type of allergy and consists of the tag, length, and value fields. Table 4 shows the specification of the defined parameters.

The *Section-205 DP* handles the plethysmographic (PLE) data samples acquired either through using a permanent rhythm or asynchronously. It contains three parts (Figure 6). The "DP Header" keeps data on the sampling rate (time interval) and the number of data blocks collected. The "Data Parameters" determine parameters for each data block (date, time, and block length). The "Data Block" keeps successive recordings of the periodically acquired PLE values.

The *Section-206 DP* keeps long-length ECG recordings or interrupted recordings. It is an extension of Section-6 of SCP-ECG, which handles the ECG waveform data. Section-206 contains three parts (Figure 7). The "DP Header" keeps data on the number (#) of data blocks collected.

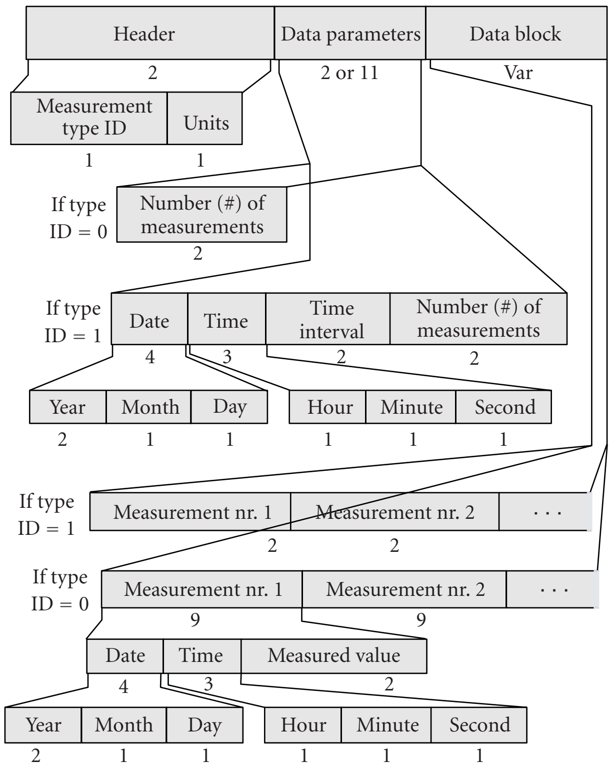

Figure 2: Overview of the data part holding the temperature data (Section-201).

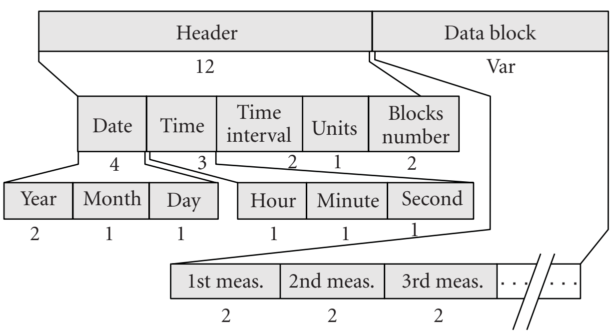

Figure 3: Overview of the data part holding the carbon dioxide data (Section-202).

The "Data Parameters" determine parameters for each data block (date, time AVM, Sample Interval, Used compression (Differential, Bimodal), 1st lead length, 2nd lead length,. . ., last lead length). The "Data Block" keeps successive recordings of the 1st lead-data, 2nd lead-data,. . ., and last lead-data. The term "lead-data" corresponds to the total acquired measurements of this lead.

The *Section-207 DP* handles positioning data (triples of Longitude, Latitude, and altitude) acquired in accordance with NMEA 0183 protocol [22]. The positioning data can be acquired either through the use of a permanent rhythm (mt = 1) or asynchronously (mt = 0). It consists of the "DP Header", which contains the "mt", the "Data Parameters", and the "Data Block" (Figure 8). If mt = 1, "Data Parameters" records

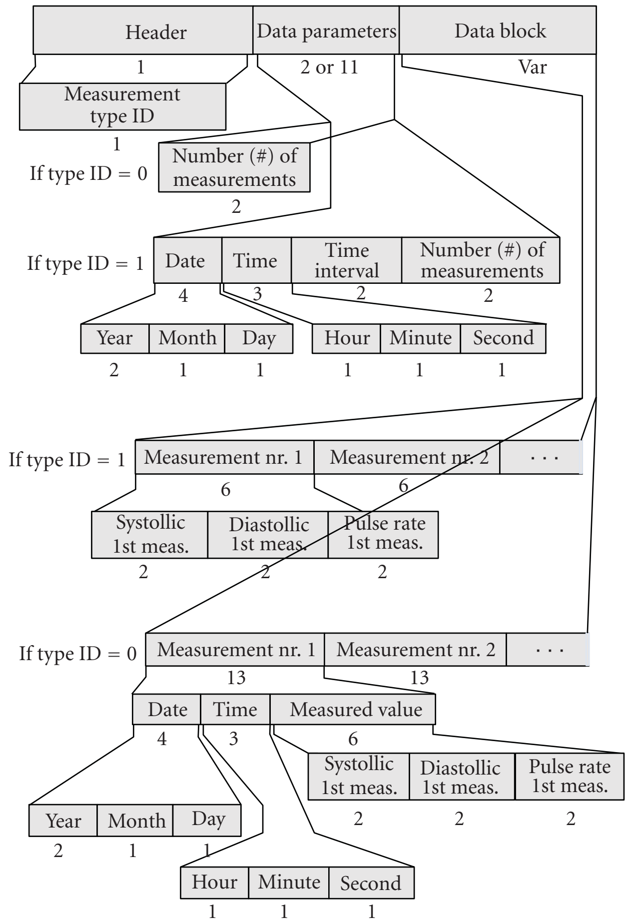

Figure 4: Overview of the data part holding the systolic-diastolic blood pressure data (Section-203).

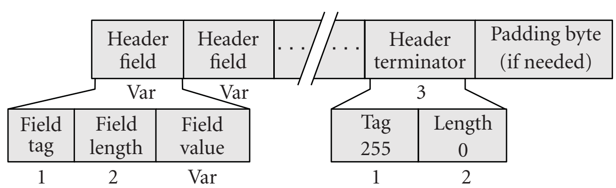

Figure 5: Overview of the data part holding the allergy data (Section-204).

Date, Time, time interval and number (#) of measurements. If mt = 0, "Data Parameters" record only the number (#) of measurements. The "Data Block" records the captured triples of measurements. If mt = 1, "Data Block" keeps the successive recordings of the periodically acquired triples of values. If mt = 0, "Data Block" keeps successive recordings of distinct measurements (Date, Time, and triples of values).

4. Implementation of a Pilot HTS Using the e-SCP ECG$^+$ Protocol

4.1. HTS Architecture. This part demonstrates the pilot implementation of the e-SCP-ECG$^+$ protocol as a software

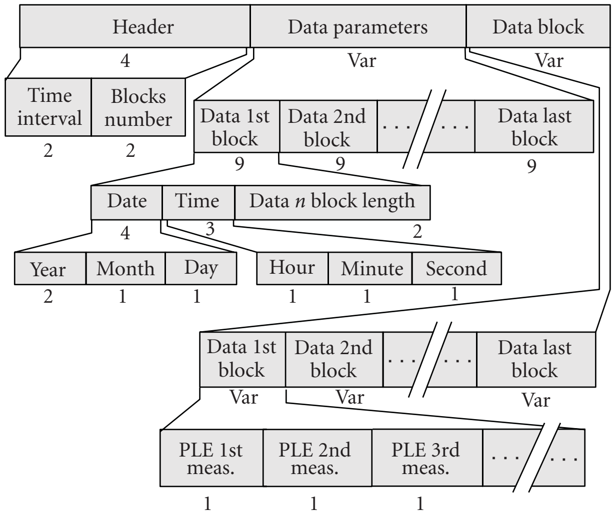

Figure 6: Overview of the data part holding the plethysmographic data (Section-205).

component. This component is integrated and evaluated in an HTS for individuals suffering from heart problems (Figure 9). The individuals' vital signs are acquired, archived, manipulated, and processed by three types of entities.

(i) Data Acquisition System (DAS). We use a wearable and a conventional portable DAS (Figure 10). The wearable DAS consists of vital sign measurement sensors (ECG, NiBP, SPO_2, Pulse Rate, Temp, and PLE) able to communicate via Bluetooth, a GPS receiver (RoyalTek RBT-1000), and a Personal Digital Assistant (PDA) device including Mobile ADSL capabilities. The wearable DAS is handled directly by the individual himself. The conventional portable DAS consists of a medical monitor (MM) (Criticare's Poet Plus 8100) acquiring vital signals (ECG, NiBP, SPO_2, Pulse Rate, Temp, PLE, and CO_2), a GPS receiver (RoyalTek RBT-1000), and a laptop (HP/Compaq nw8440) device including Mobile ADSL capabilities. The portable DAS is handled by a technician or a doctor and is already tested on another telemedicine system whose general architecture has been analyzed in [23] (without the GPS capability). The demographic and allergy data are introduced manually into PDA and laptop devices. The collected information in these devices is automatically organized in e-SCP-ECG$^+$ files for local storage and forwarded to a remote expert's site for monitoring.

(ii) Remote Health Monitoring System (RHMS) Covers the Expert's Site. It consists of a PC including a special application for opening e-SCP-ECG$^+$ files and modifying, storing, presentation, and processing of the acquired data. It also includes procedures for comparing old and new measurements.

(iii) Storage Unit (SU) For Temporary Storage and Archiving of the Received Files. The DASs in the pilot HTS were used for the remote monitoring of twenty-seven individuals. The monitoring of these individuals was performed by two RHMSs, located one in the Cardiology Department of Aegion General Hospital and the other at the doctor's private site. This department works as the Telemonitoring Centre (TC), also including the SU. The DASs communicate with RHMS using public Fixed and Mobile ADSL.

4.2. Analysis of the Health Monitoring Process. The DASs send the e-SCP-ECG$^+$ files to the RHMSs through the SU. The SU has the responsibility to keep the whole body of information permanently in dedicated spaces. This Client/Server (C/S) scheme permits centralized control of the monitoring process, allowing efficient switching of the received files among different RHMSs. The monitoring process is performed by experts operating the RHMSs. The switching capability facilitates the doctors' mobility and the use of different RHMSs without losing contact with the total archives. The switching request in this implementation is initiated by one RHMS user and contains the receiver RHMS ID.

The monitoring process employed is distinguished by a basic and an emergency operational mode. In both modes, the monitoring process requires real-time recording of the individual's vital sign, context, and geolocation data. The recorded data are included within one file and sent to the RHMS.

The basic mode is applied during the detection of normal health conditions of the individual. The type and the recording period of the medical data are directly related to the individual's health condition (status); this status is supposed by the doctors applying medical criteria. The basic mode distinguishes recording periods of 1, 5, 15, 30 minutes as well as 1, 2, 3, 6, 12, or 24 hours. Each recording includes one examination per biosignal type. Each ECG examination contains data acquired by all leads during an at least 10 second measurement time duration (depending on doctor's decision), and by using a sampling rate of 500 samples per sec and per lead. Hence, the ECG examination data are approximately (at least) 10 Kbytes per lead.

The emergency mode is applied when an individual's abnormal health conditions are detected. This mode uses an enhanced periodical evaluation of the whole body of acquired data (e.g., short recording period of 30 seconds, continuous recording).

The basic and emergency monitoring processes require the creation and transmission of e-SCP-ECG$^+$ files that include a different amount of data each time. The proposed structure allows the dynamic manipulation of these, data, since the structure of all sections allows several examinations to be successively recorded within a file. Hence, the use of the e-SCP-ECG$^+$ empowers doctors to apply monitoring processes fully tailored to the real needs of the individuals.

The overall communication between the entities is ensured by exchanging control and signaling data. The transition from basic to emergency mode is performed either manually, by the user himself using the emergency button either by the RHMSs user, or automatically if any change is detected in the acquired Temp, Pulse Rate,

Table 4: Definition of Data Part of Section-204 (Allergy).

Tag	Length	Value (Parameter Data)			
1	3	Rhinitis (Binary)			
		This has the following format:			
		Byte	*Contents*		
		1	Binary: type of rhinitis		
			0: all year		
			1: seasonal		
			2: all year with Conjunctivitis		
			3: seasonal with Conjunctivitis		
		2	if seasonal, then appears on Month:		
			Bit 0 January	Set = Yes	Reset = No
			Bit 1 February	Set = Yes	Reset = No
			Bit 2 March	Set = Yes	Reset = No
			Bit 3 April	Set = Yes	Reset = No
			Bit 4 May	Set = Yes	Reset = No
			Bit 5 June	Set = Yes	Reset = No
			Bit 6 July	Set = Yes	Reset = No
			Bit 7 August	Set = Yes	Reset = No
		3	if seasonal, then appears on Month:		
			Bit 0 September	Set = Yes	Reset = No
			Bit 1 Octomber	Set = Yes	Reset = No
			Bit 2 November	Set = Yes	Reset = No
			Bit 3 December	Set = Yes	Reset = No
2	3	Asthma (Binary)			
		This has the following format:			
		Byte	*Contents*		
		1	Binary: type of rhinitis		
			0: all year		
			1: seasonal		
		2	if seasonal, then appears on Month:		
			Bit 0 January	Set = Yes	Reset = No
			Bit 1 February	Set = Yes	Reset = No
			Bit 2 March	Set = Yes	Reset = No
			Bit 3 April	Set = Yes	Reset = No
			Bit 4 May	Set = Yes	Reset = No
			Bit 5 June	Set = Yes	Reset = No
			Bit 6 July	Set = Yes	Reset = No
			Bit 7 August	Set = Yes	Reset = No
		3	if seasonal, then appears on Month:		
			Bit 0 September	Set = Yes	Reset = No
			Bit 1 Octomber	Set = Yes	Reset = No
			Bit 2 November	Set = Yes	Reset = No
			Bit 3 December	Set = Yes	Reset = No
4	length	Medical Allergy or Drug Allergy (Binary)			
		This has the following format:			
		Byte	*Contents*		
		1	binary: set equal to 255		
			0-Unspecified		
			1-Penicillin,		
			2-Sulfa antibiotics,		

Table 4: Continued.

Tag	Length	Value (Parameter Data)	
			3-Allopurinol,
			4-Seizure and anti-arrhythmia medications,
			5-Nonsteroidal anti-inflammatory drugs (such as aspirin and ibuprofen),
			6-Muscle relaxants,
			7-Certain post-surgery fluids
			100-Other
		This field contains a list of the patient's allergy on foods. There is no limit of inputs. Each input shall be represented by one byte	
5	length	Food Allergy (Binary)	
		This has the following format:	
		Byte	*Contents*
		1	binary: set equal to 255
			0-Unspecified
			1-Fish and shellfish
			2-Peanuts
			3-Tree nuts, such as walnuts
			4-Eggs
			5-Cow's Milk
			6-Wheat
			7-Soy
			100-Other
		This field contains a list of the patient's allergy on foods. There is no limit of inputs. Each input shall be represented by one byte	
6	length	Other Allergy (Text characters)	
		This field permits free text comments about other type of allergies.	

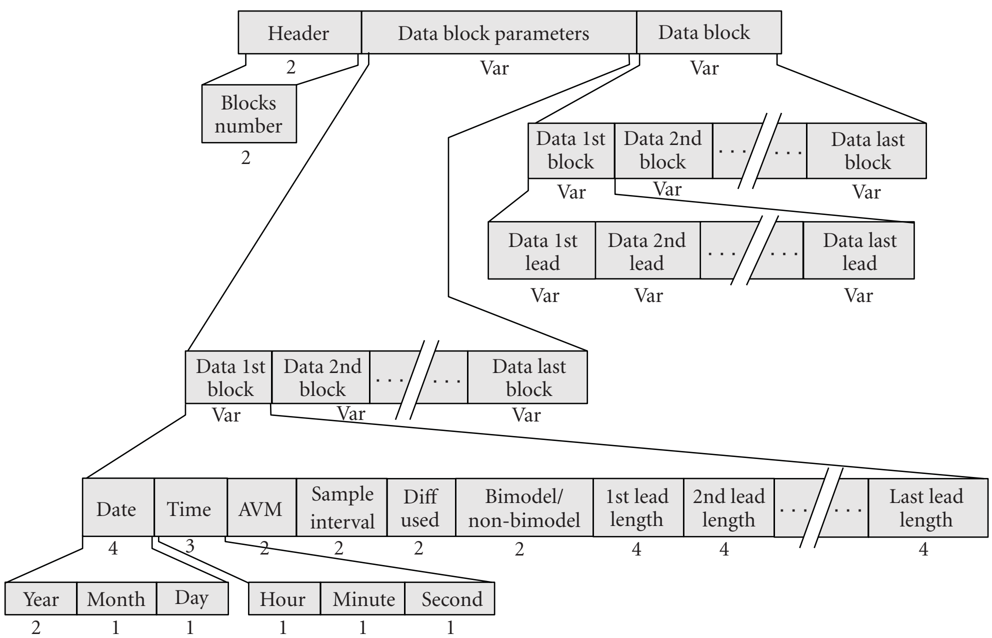

Figure 7: Overview of the data part holding the extended ECG data (Section-206).

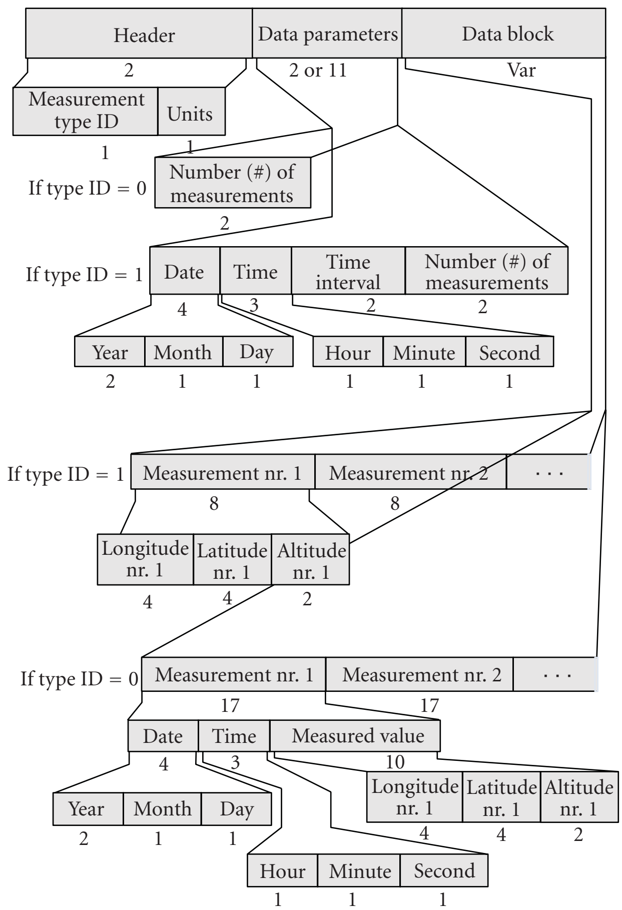

FIGURE 8: Overview of the data part holding the GPS data (Section-207).

CO_2, and SPO_2 values. In the present implementation, the ECG's abnormalities are detected by the evaluator. Algorithms for the automated detection of these abnormalities have not been used.

4.3. Implementation Issues. Figure 11 presents the overall processes employed in the implemented system. The DAS performs User Authentication (UA), Data Acquisition, File Creation, and local data demonstration (Display).

The RHMS performs the UA, Search-Query of archived files, and the Display, Processing, Printing, and Modification of each new file. The modification process allows the user to add diagnostic reports to the received information. The Display processes include dynamic measurement and switching of presentation facilities (change of sensitivity, display speed, zoom of graphical representations) to be applied to ECG signals. The Processing allows comparison of examinations taken on different dates. The comparison is performed directly among arithmetic data or through the superimposition of waveforms and subject evaluation. Figure 12 depicts the main screen of the RHMS.

The SU performs the Temporal Storage and Archiving of the files in an appropriate patient database/file system. The

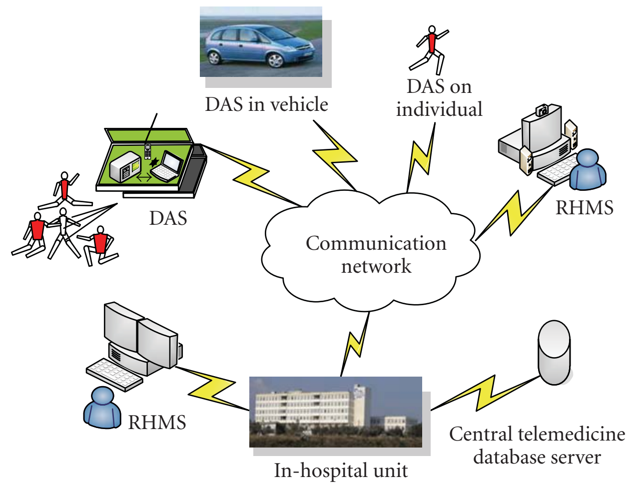

FIGURE 9: Structure of the designed Health Telemonitoring System.

Archiving process handles issues such as reading of files, storing of critical information in the data base, and keeping the original files in a suitably configured tree structure in the disc cluster. The critical information includes the demographic elements, examination date, case subject data, and diagnosis, and it is used for querying purposes any time an expert wants to retrieve an examination. The SU also contains the Users' Catalogue. This User's Catalogue is typically referred to as User Profiles. From the patient's perspective, these profiles could host information such as demographic and personal data as well as crucial information to determine the patient's medical status such as alerting thresholds of physiological parameters [24]. From the medical staff perspective, user profiles host information on personal data, medical specialty, and so forth as well as the list of the patients admitted to each doctor [25] and the availability status.

4.4. Security Issues. In the presented implementation, security was provided both during data transmission and upon each user's access.

For the sake of security, the data collected in DAS comprising the e-SCP-ECG$^+$ file were encoded before transmission [1, 26]. The improvement of coding efficiency was achieved by using the Base64 code.

On the other hand, the UA process performs the authentication of the involved (individuals, technicians, physicians, etc.) by establishing the identity of the person and verifying the validity of transferred data. User identification is ensured through a log-in screen that requires a unique id and a unique password for any user to enter. Users already registered in the Catalogue are authorized according to their static role (access privileges, certifications, etc.). These roles are also recorded in the Catalogue to continue a specific navigation inside the data and services provided by the HTS. The access rights of each user, which constitute his individual static role, are defined by his medical specialty. The full data of each user login (user, date, time, etc.) are kept as a user's history.

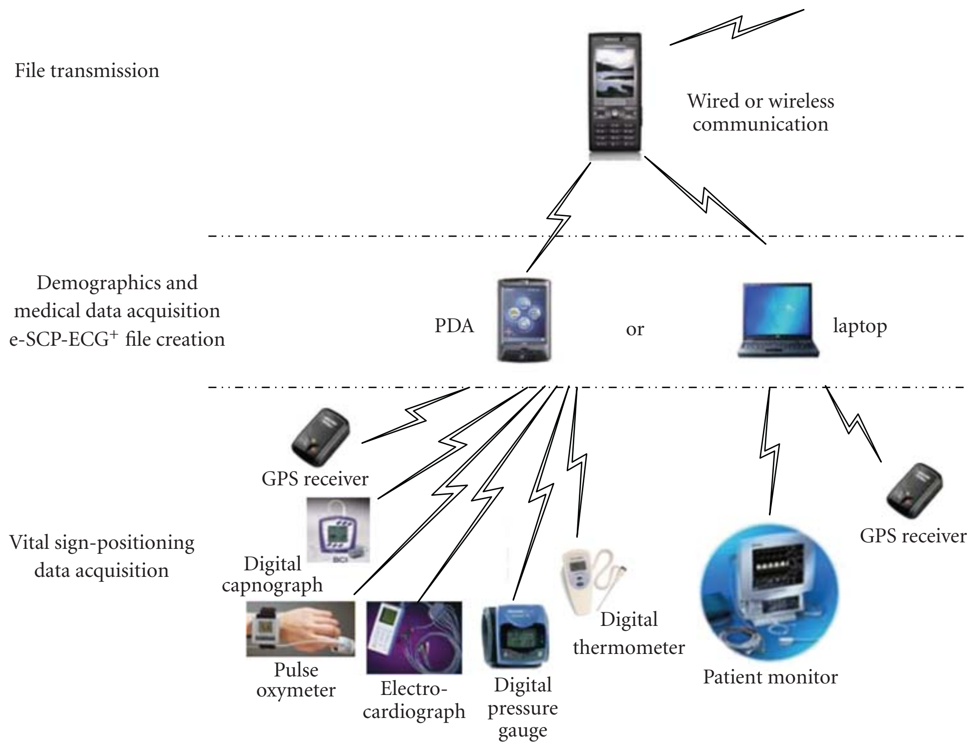

Figure 10: Overview of data acquisition, file preparation, and transmission.

5. Discussion

In order to test the correctness of the proposed extensions, we had to create an SCP-ECG Writer and an SCP-ECG Reader [27, 28]. The SCP-ECG Reader and Writer are software modules entirely written in Visual Basic. During the evaluation of the reader, we used files from the OPENECG portal (established in order to provide help in future protocol implementers) and also from manufacturers such as TAPUZ, QRS, and PROMED PLUS-cardioSCP. Afterwards, we added the e-SCP-ECG+ extensions. The new protocol is designed to be flexible, having an adaptive structure. Handling only the data that characterize each medical incident, it achieves minimum transmission time and also easier management. This attribute makes it ideal for a wide area of applications, such as the transmission of patient data to a reception center, the creation of a medical patient database, and so forth.

The e-SCP-ECG+ protocol incorporates two fields in its structure in order to set file access rights or to restrict file access. The first field is used in cases where the modification of a file is prohibited. The second one defines the data types accessible to the user. For example, a file can be marked as fully accessible to a specific doctor category/specialty and partially accessible or not accessible to other categories of doctor. This restriction is necessary to ensure that selected experts can access the file contents in order to make the correct diagnosis. The medical specialties and the corresponding restrictions are stored in an appropriate table in DAS's local Database, which is updated through the TC's database server.

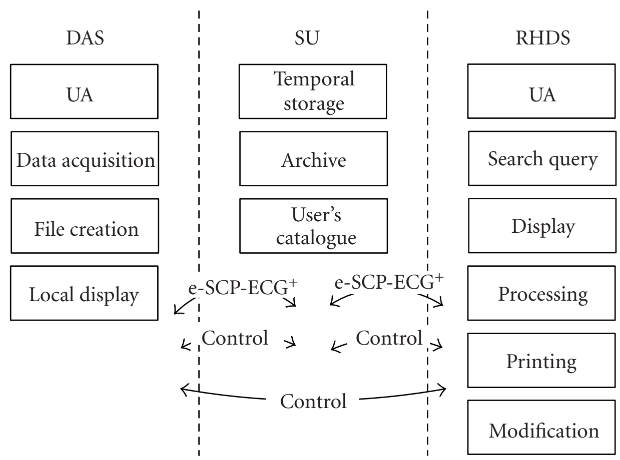

Figure 11: Applications flow diagram.

The e-SCP-ECG+ protocol ensures data continuity. In many cases, the acquired measurements are not continuous. There are vital signs, such as blood pressure, which can be measured periodically (at defined intervals) or at random time intervals. Also, a measured vital sign can be interrupted for a period in order a special treatment to be applied to the patient. According to the type of acquired data, the e-SCP-ECG+ handles measurements as continuous, distinct, repeated (at specific intervals), or interrupted parts of continuous measurements.

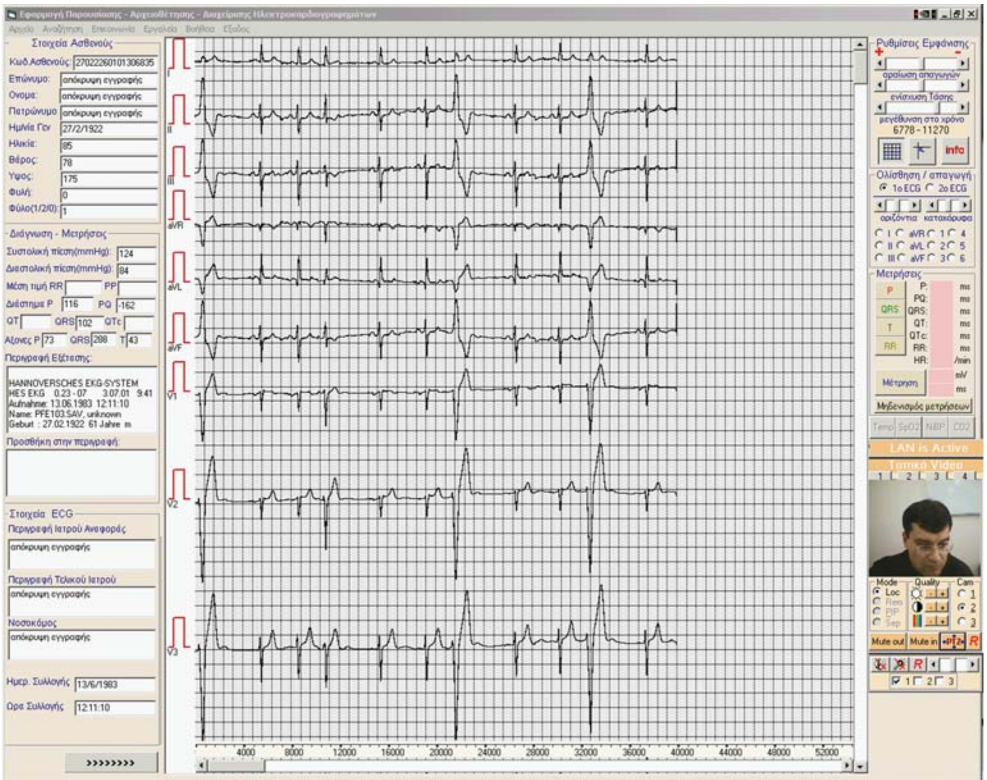

Figure 12: The main screen of the used application on RHMS.

Table 5: Patient included in the evaluation-attributes.

Age	Patients Equipment		Malfunctions		
	Wearable	Conventional	Heart	Respiratory	Allergies
30–40	3	2	5	3	
41–50	9	6	15	7	2
51–60	2	5	7	1	3

The e-SCP-ECG$^+$ protocol is designed to overcome the time length limitation of the SCP-ECG protocol. The SCP-ECG protocol handles a limited volume of ECG rhythm data ([9]—Section-6§5.9.3). It defines the length for each lead as a two-byte integer storing for each lead to at most $256 + 256 * 256 = 65792$ bytes. Because each measurement is stored as a two-byte integer, the maximum number of allowed measurements for each lead is $65792/2 = 32896$. Assuming that any given ECG machine has an acquisition rate of 500 samples per second (no compression is used), the protocol restricts the acquired data to 65.8 seconds. As an improvement, the e-SCP-ECG$^+$ protocol defines the length for each lead as a four-byte integer, each lead therefore holding a maximum of more than 4.311.810.304 values or 2.155.905.152 measurements, which corresponds approximately to 1.200 hours of measurements (with a device acquiring 500 samples per second).

This implementation targets the evaluation of e-SCP-ECG$^+$ protocol under real world operation. The pilot HTS has been implemented in order to evaluate the e-SCP-ECG$^+$ protocol and was not indented to demonstrate the advantages or the disadvantages of various devices that were used for the collection of vital signs from the human body.

Our prime intention to include all patients who visited the cardiology department of the General Hospital of Aegion during the evaluation period proved impossible because only 60% satisfied the requirements of this study. Their unfamiliarity with the IT systems or with the placement of the sensors used to acquire vital signs was the major problem. The individuals chosen were middle aged (30–60), familiar with IT systems to an acceptable extent, and collaborative. Thus, we ensured the best conditions to evaluate the HTS. All sampled individuals suffer from heart diseases, whereas some of them suffer from hypertension, respiratory, and/or allergies. Table 5 presents the distribution of participants per kind of equipment, disease and age zone.

During a five-month pilot period of HTS operation we aimed to evaluate its reliability. The twenty-seven (27)

Table 6: Patient's questionnaire subset.

Question on ...	A	O	Θ
System's characteristics			
(1) System's reliability: error frequency	11	33	56
(2) Convenience on sensor placement	4	52	44
(3) Measurement device maintenance (charge,clearance...)	0	11	89
Personal data			
(1) Convenience on data input	4	19	78
(2) Are there data unethical or abusive?	0	15	85
(3) Are there data difficult to collect?	0	4	96
System's learning			
(1) Learning of device operation	0	30	70
(2) Learning of used software/application	0	30	70
Communication with other systems—users			
(1) Data transmission to the Data Reception Center	4	44	52
(2) Communication with Doctors in case of a health problem	0	7	93
Difficulties during the usage			
(1) Movement with the sensors in place	19	33	48
(2) Sensor slip during movement	7	19	74
(3) Limitations provided by sensors usage	22	30	48
(4) Irritations caused by sensor usage	74	22	4
Total system's satisfaction			
(1) System's reliability	4	22	74
(2) System's operation satisfaction	0	22	78

A: Negative (checked: −2, −1); O: Neutral (checked 0); Θ: Positive (checked: 1, 2).

individuals selected suffer from heart diseases and had prehospital notification. Fourteen (14) individuals used wearable DASs, while the other thirteen (13) used conventional portable DASs. The evaluation of the received data was performed by 3 doctors.

The wearable DASs employed are not embedded in clothes but are composed of discrete devices communicating with the PDA through wireless network. The use of discrete device interfacing groups and a family of sensors (e.g., ECG, CO_2) is not practical for continuous use due to device volumes, sensor placement, and consequent discomfort. These devices need more care (cleaning, charging, etc.). The gels used in the electrodes dry out after a period of usage, which leads to incremental contact resistance and the subsequent degradation of signal quality. The gels used in the electrodes cause irritation and rushes when used for long periods. The usage of the conventional electrodes requires suitable preparation of the skin if it is hairy. The acquired signals are affected by motion artifacts and the baseline wanders as the electrodes float on the layer of gel.

We also encountered some more problems [29] such as the usage of nail polish which prevents the correct operation of SPO_2 sensors or cold temperatures or high altitudes, which leads to lower flow of blood in the peripherals resulting in wrong SPO_2 measurements. These above presented difficulties kept us from achieving long-term monitoring of individuals. Hence, the monitoring process for each individual was limited to a maximum of four hours per day for two or three days per person. Nevertheless, this time is adequate to indicate the overall performance of the e-SCP-ECG$^+$ protocol. The availability of a limited number of devices also prevented us from performing long-term evaluation.

On the other hand, the conventional portable DASs were utilized in cars during individual transportation from the city of Patras to the city of Aegion, and vice versa. In this case, the difficulties we faced were the bulkiness of the acquisition device and laptop and also the hampering of the wires used to connect the individual to the acquisition device. The length of usage of the devices in this case was equal to the transportation time.

Before the initial HTS operation, we had to inform the individuals about the system, the placement of the sensors on their body, the operation of the devices, and the way they are charged.

In order for HTS to be efficient and to overcome possible interrupted transmissions, due to the topology or due to the lack of a High-Speed Packet Access (HSPA) signal, we decided to perform continuous creation and transmission of data snapshots [30] following a predefined interval. Each

Table 7: Doctor's questionnaire subset.

Question on ...	A	O	Θ
System's characteristics			
(1) System's reliability: error frequency	0	0	100
(2) Workstation switching	0	0	100
(3) Incident presentation	0	33	67
Data			
(1) Data integrity	0	0	100
(2) Data resolution	0	0	100
(3) Ability to make diagnosis using the received data	0	0	100
System's learning			
(1) Learning of device operation	0	0	100
(2) Learning of used software/application	0	0	100
Communication with other systems—users			
(1) Data reception to the Data Reception Center	0	33	67
(2) Communication with Patients in case of a health problem	0	67	33
Total system's satisfaction			
(1) System's reliability	0	0	100
(2) System's operation satisfaction	0	0	100

A: Negative (checked: −2, −1); O: Neutral (checked 0); Θ: Positive (checked: 1, 2).

snapshot was defined to be an e-SCP-ECG$^+$-formatted file. The interval was selected by the system operator and differed according to each patient's health status, location, and activities. The e-SCP-ECG$^+$ files received by the SU in the TC, after their processing (extraction of critical information), are available to experts. The files concerning the same incident, post diagnosis, were merged and archived in order to form a clinical history database per patient for future comparisons.

The file transportation scenario employed through the server was selected for two reasons. Firstly like SCP-ECG, the e-SCP-ECG$^+$ standard is not very suitable for real-time transmission of biosignals (e.g., ECG) though it is very flexible and suitable for the storage of the data snapshots acquired. Secondly, it offers the possibility of switching between two RHMSs without loss of data.

At the end of the five-month pilot period of the HTS, patients asked to complete a questionnaire about their experience on system's usage. Table 6 presents a subset of the used questionnaire and also the percentage given by patients on each category.

The participating doctors had also completed questionnaires relative to the systems response and usefulness. Table 7 presents a subset of the used questionnaire and also the percentage given by patients on each category.

6. Conclusions

This paper has introduced the extension of SCP-ECG protocol to e-SCP-ECG$^+$ protocol in order to satisfy health telemonitoring needs, as required by cooperating doctors during various telemedicine projects in the past [3, 4, 23]. The e-SCP-ECG$^+$ protocol adds the capability of handling more demographics data, extra vital signs such as the SPO_2, the CO_2, the NiBP, the Temp, and the pulse rate, and also data relative to allergies. The extensions are made both as additions to existing sections and as new sections for the SCP-ECG protocol following its structure.

In order to evaluate the e-SCP-ECG$^+$, we implemented the protocol as software components that integrated into a pilot HTS. Using the HTS we tested the ability of the above protocol to handle the collected information.

The e-SCP-ECG$^+$ protocol can be integrated into medical systems for administration of patient examination data. Alternatively, it can be used to form a service providing experts with the whole body of information about a patient's health status, leading to a more accurate diagnosis as well as more appropriate treatment. This protocol can also be used in Ubiquitous Health monitoring (UHM) systems managing the collected information. The Protocol's adaptive structure permits the management of data characterizing each particular event (incident), leading to shorter transmission and process times and minor storage space needs.

Abbreviations

ADSL: Asymmetric Digital Subscriber Lines
DAS: Data Acquisition System
BAN: Body Area Network
C/S: Client/Server
DP: Data Part
ECG: Electrocardiograph
HSPA: High Speed Packet Access

HTS: Health Telemonitoring System
MM: Medical monitor
NiBP: Noninvasive blood pressure
P2P: Peer-to-peer
PDA: Personal digital assistant
RHMS: Remote Health Monitoring Station
SU: Storage Unit
TC: Telemedicine Center
Temp: Body temperature
UHM: Ubiquitous Health Monitoring
UA: User Authentication.

Acknowledgments

The authors are grateful to D. Kontogiannis from Intrasec S.A. who has provided them with the software for vital sign data reception from the Criticare's Poet Plus 8100 Vital Sign monitor, which is used in conventional DASs. The presented work comprises a part of the doctoral thesis of the first author. The thesis is available online [31].

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 450418, 13 pages
doi:10.1155/2010/450418

Research Article

Using Exploratory Focus Groups to Inform the Development of Targeted COPD Self-Management Education DVDs for Rural Patients

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Received 15 September 2009; Revised 2 April 2010; Accepted 7 May 2010

Academic Editor: George Anastasopoulos

This exploratory study assessed the self-management learning needs, experiences, and perspectives of COPD patients treated at a Certified Federal Rural Health Clinic to inform the development of a COPD self-management DVD. A purposive, homogeneous sample of COPD patients participated in focus group interviews. Data from these interviews were referenced to edit a library of Rvision COPD self-management DVDs into a single condensed DVD containing only the most pertinent self-management topics. Patients reported a lack of knowledge and skill development related to purse lipped breathing, controlled coughing, and stress management; while medication management skills were found to be quite adequate. Engaging rural communities in formal qualitative inquiries to describe COPD specific needs for self-management may lead to future use of educational technologies aimed at improving quality of life for these rural, hard to reach populations.

1. Introduction

Chronic obstructive pulmonary disease (COPD) is a preventable and treatable disease, characterized by progressive airflow limitation that is not fully reversible and is associated with an abnormal inflammatory response of the lung to noxious particles or gases [1]. Airflow limitation is signified by two specific respiratory diseases, emphysema and/or chronic bronchitis. Dyspnea, or shortness of breath, is the hallmark symptom of COPD and is a major cause of disability and anxiety associated with the disease. The prevalence, morbidity, and mortality associated with COPD are generally directly related to the prevalence of tobacco smoking and increased age [2]. COPD is the fourth leading cause of death in the United States (following heart disease, cancer, and stroke) and is the only major cause of death in America for which no significant decrease in morbidity or mortality has been observed over the past 20 years [3, 4]. In effect, by the year 2020, COPD is estimated to be the 3rd leading cause of death and 5th leading cause of disability in the world [5, 6].

COPD patients are faced with multiple health responsibilities, such as preventing and managing shortness of breath and handling prescribed medications. It has been suggested that healthcare professionals focus attention on the care processes necessary for patients to cope with complications that arise due to this debilitating disease [7]. *Disease management* is an approach which coordinates resources across the health care system with the aim of increased patient knowledge and control over disease [8]. For COPD patients, pulmonary rehabilitation is one such disease management option. These programs are usually hospital run and include supervised regimens of physical exercise, behavioral modification, nutrition counseling, and disease education. The first enrollment in pulmonary rehab is normally covered by Medicare for patients who qualify; however, patients who wish to continue rehabilitation after the first round of therapy must usually pay for it out of pocket. This type of maintenance program can prove to be quite costly for patients, especially those with limited monetary resources. Therefore, attempts at COPD *self-management* in the home environment, with no requirements for specialized facilities or group meetings, are ideal.

COPD self-management refers to engaging in activities that promote adequate inhalation technique, building physiologic reserves, preventing adverse health outcomes, complying with recommended treatment protocols, monitoring respiratory and emotional status and making appropriate management decisions on the basis of this self-monitoring, and managing the effects of illness on self-esteem and coping skills [9]. Chronic disease self-management programs promote active patient participation and focus on acquisition and implementation of learned skills and enhancing patient self-confidence related to disease management decision making [10]. In systematic reviews of the efficacy of COPD self-management education programs, an association was established between self-management education and improved health-related quality of life (HRQoL), with no indication of detrimental effects on other related health outcomes [11]. In light of the effectiveness of some COPD self-management programs, health educators have been encouraged to develop cost-effective, readily accessible interventions which (a) define the true effective educational elements of COPD self-management and (b) facilitate the acquisition of self-management skills and behavior change. Previous work indicates that adults use a variety of strategies to adapt to chronic disability [12], each of which may impact health and health-related quality of life (HRQoL) in unique and disparate ways. Moreover, understanding self-management behaviors is complex and represents a “black box” for health care professionals [13].

It is known, however, that targeted health education plays a vital role in improving skills, coping ability and HRQoL among patients with COPD [14–16]. Targeted patient education may not improve exercise tolerance or lung function, but it can have a dramatic impact on patients’ ability to deal with the disability caused by COPD. Rabe and colleagues advise that, “Education should be…directed at improving quality of life, simple to follow, practical and appropriate to the intellectual and social skills of the patient” [1, page 541], given that patients differ in terms of the depth and type of information that they seek [17]. Moreover, patient-centered education developed in accordance with specific needs is a key factor in managing COPD [18, 19]. Information needs assessments attempt to ascertain the opinions of learners regarding what information *they* want to learn, what educational topics *they* believe are important and which self-management topics *need* to be addressed [20].

Given time constraints, the majority of primary care physicians are unable to provide sufficient “in-person” education to patients regarding COPD self-management. In addition, some physicians do not feel prepared to teach patients within the clinical environment due to the low priority that patient education is given by managed care administrators. The absence of third-party reimbursement to support patient education makes teaching and learning between provider and patient quite difficult. This is problematic, because patients report not having their disease-related concerns addressed during routine consultations [21]. Patients suffering from COPD report widespread dissatisfaction with the self-management education they are provided [22, 23]. Because of this, some COPD patients do not feel connected to their health care provider, which affects patient decision making when attempting to manage disease [24]. COPD patients prefer to be involved in their own medical decision making and respond better if they are included in the process [25, 26].

2. Literature Review

Undoubtedly, there seems to be a paucity of patient-centered interventions that take into account differing patient perspectives and knowledge of COPD self-management by way of a needs assessment [27]. This is disappointing, given that patient educators are taught to recognize dissimilar concerns brought to light across divergent populations [28] and develop programs in accordance with a mutually understood care plan [10]. Qualitative inquiry can assist practitioners in developing programs which address self-management issues valued by patients. Focus group interviews have proven to be a useful research technique for identifying older adults’ beliefs and needs regarding specific health topics. Cicutto et al. [13] conducted focus groups with a purposive sample of patients suffering from COPD in order to understand the self-management activities of COPD patients and the meaning that patients associate with these activities. Constant comparative analysis was used to examine focus group transcripts. The major theme which emanated from these focus group sessions centered on the idea of “surviving COPD,” which ultimately included adjusting physically and emotionally to COPD in order to achieve a satisfactory HRQoL. A common adjustment adopted by patients was a shift towards more planning, pacing, and prioritizing for activities of daily living and disease management [13]. Planned, energy-saving activities included breathing exercises, slow walks, and more sedentary forms of recreation. Breathing exercises, along with medication management, were identified as useful strategies for enabling activities of daily living. Aerobic and strengthening exercises were identified as dispensable due to lack of motivation and unpleasant feelings following physical exertion. One limitation of this study was the lack of representation among racial and ethnic minorities, whom may have separate and distinct perspectives of COPD self-management.

In order to understand statistically nonsignificant results of a quantitative investigation measuring change in HRQoL after COPD self-management intervention [29], Monninkhof et al. [30] conducted in-depth interviews with a purposive sample of 20 participants. Patients reported that self-management education helped them distribute energy evenly, control symptoms more effectively, and manage medication intake. Increased confidence coping with disease symptoms was also reported, which corroborated findings by Camp et al. [31], who characterized patient confidence over chronic disease as an important mediating variable along the continuum from self-management skill adoption to HRQoL improvement.

3. Rationale and Theoretical Framework

Older adults suffering from COPD have unique preferences for the manner in which they obtain self-management education [32, 33]. It has been suggested that older COPD patients appreciate and learn well from home-based educational programs that offer audiovisual media to transmit targeted self-management instruction [34–38]. In light of this, type III translational research should focus on disseminating innovative educational material through readily available technology in order to provide underserved COPD patients with customized resources. The aim of the present study was to assess the self-management learning needs, experiences and perspectives of COPD patients who were treated at a Certified Federal Rural Health Clinic in order to inform the development of a COPD self-management DVD.

There were two research questions developed to achieve the primary aim of the study: (1) what are the self-management experiences of patients with COPD who live in a rural setting? and (2) how do patients perceive the effects that self-management can have on their HRQoL?

Mass communication technologies can be utilized to provide patients with self-management skill development products which can help enhance self-management self-efficacy beliefs. Theories of *consumer information processing* (CIPT) provide a framework for understanding why people do or do not pay attention to, understand, and/or make use of consumer health information [39]. CIPT postulates that information must not only be available but also be wanted and believed useful by the consumer. Further, the consumer must possess the time and level of comprehension necessary to process the information presented, as consumer decision making involves multiple stages of acquiring, processing, learning, using and evaluating information [39, 40]. A central premise of CIPT is that individuals can process only a limited amount of information at one time [40]; thus, the information must be presented in such a way that the patient is able to comprehend the information that is provided.

4. Methods

Focus groups were conducted in hopes of achieving data saturation (i.e., no longer hearing new information), which would provide understanding as to the meaning that COPD patients associate with COPD self-management. Qualitative data yield thick and rich descriptions which are contextualized based on the multicausal experiences people endure [41]; thus, this type of inquiry makes sense of experiences by uncovering the meanings that people associate with various events [42].

4.1. Setting. COPD patients were recruited from a Certified Federal Rural Health clinic located in Butler, Alabama. Butler is a rural town located in Choctaw County, a low socioeconomic district. In 2003, it was reported that almost 20% of the population in Butler lived below the poverty line [43]. Twenty-four percent of Choctaw County is farmland, and Choctaw is one of 42 counties classified as "rural" in Alabama [44], with rural being defined as population living in towns outside a commuting zone of larger urban areas. Butler is one such diverse, rural municipality, with 43.9% of its citizens being of African-American decent, and 52.8% being female. In addition, over 15% of Butler's population are comprised of citizens over 65 [43]. Choctaw County has been designated as a Health Professional Shortage Area by the Federal Office of Health Professions [45].

4.2. Sample. A purposive, homogeneous sample of COPD patients was recruited within Choctaw County using various proactive recruitment strategies such as physician referrals, newspaper advertisements, and telephone contacts. Homogeneous sampling was utilized, because participants needed to possess a clinical diagnosis of COPD. This sampling approach is often used to select focus groups [46]. Within each of two focus groups, 6 patients were recruited. This number was selected for each group based on three reasons: (a) best practice minimum recommendations for focus group research [47, 48] and (b) the desire to obtain an in-depth understanding of the topic and high involvement from the participants [47]. The inclusion criteria for participation were: (a) adults 50 years of age or older, (b) clinical diagnosis of COPD (i.e., chronic bronchitis or emphysema), (c) presence of dyspnea, and (d) provision of informed consent. The exclusion criterion for participation was past participation in structured pulmonary rehabilitation programs wherein self-management activities were pre-selected.

4.3. Procedures. Preliminary information, such as patient medical diagnosis and age, was obtained through a telephone interview with potential patients. Interested patients were screened for gender and race/ethnicity to ensure comparable numbers of men and women and desired diversity of race. In addition, patients were asked to report their age, marital/relationship status, educational level, income and living arrangements. Informed consent was obtained from each participant before their participation. Each participant was provided with refreshments during the one-hour focus group along with a $20 honorarium for their participation. Institutional Review Board (IRB) approval for this study was secured. At the end of each focus group session, member checking was done to confirm the initial interpretations of the mediator and to enhance the descriptive and interpretive validity of the data analysis [49]. Focus group interviews were transcribed using paper and pencil with the aid of a digital audio recorder. Appendices A and B describe the rubric used by the moderator to conduct the interviews.

4.4. Data Analysis. Focus group data was analyzed using three distinct qualitative analysis tools: (a) method of deductive constant comparison; (b) classical content analysis, and (c) word count. Three tools were used to analyze the same data at the request of Leech and Onwuegbuzie [50], who state that using more than one type of analysis can augment the rigor and trustworthiness of qualitative findings through methodological triangulation. Constant comparison analysis [51] or "coding" was undertaken deductively to identify general, underlying themes within the focus group data.

The entire data set acquired during the present study was read over and chunks of data (i.e., related portions of the transcript) were grouped into meaningful parts. Following this, the chunks were assigned to inductive codes which emerged. To determine the frequency of themes identified within the data, a classical content analysis procedure was employed to further augment the findings from the method of constant comparison [50]. Instead of creating themes from emergent codes, the number of times each code emerged was quantified for saturation across the focus group interviews. This was done to understand which codes were used most, thus cultivating a greater understanding of the most important concepts reported by the interviewees. If a greater number of codes were identified within a certain thematic category, then that category was deemed to be more relevant. Lastly, a word count method was used to quantify the number of times a specific word was used during the focus group discussions. Word count is especially useful for focus group analysis, because counts can help identify words spoken the most and those spoken the least. More important and noteworthy words were hypothesized to be used more often [52], thus providing more meaning from the conversation descriptions [53]. Additionally, word count assisted the researcher in identifying patterns, verifying hypotheses and maintaining analytic integrity and rigor [54].

5. Results

Each of the focus groups ($n = 2$) was held in a group meeting room. Table 1 describes the demographic characteristics of the 12 focus group participants. Over half of the participants were female, and the majority did not finish high school. All participants reported an annual income between \$15,000 and \$24,999; thus, participants were of low socioeconomic status. Half of the focus group participants were married, yet an almost equal proportion were widowed (33.33%) or single (16.67%). The overwhelming majority of participants (83.33%) lived with family, and the mean number of years participants reported being diagnosed with COPD was variable (mean = 6 years; SD = 4.43 years). Patients included in each of these focus groups represented both Caucasian and African American races.

Table 1: Focus group demographic characteristics.

Characteristics	$n = 12$
Age (mean ± SD)	67 years ± 8.07 years
Gender	
Male	4
Female	8
Race	
Caucasian	7
African American	5
Educational level	
Grade school	6
Some high school	2
High school graduate	2
Some college	0
College graduate	2
Graduate degree	0
Income	
Less than \$14,999	0
\$15,000–\$24,999	12
\$25,000–\$34,999	0
\$35,000–\$49,999	0
\$50,000–\$74,999	0
\$75,000–\$99,999	0
\$100,000+	0
Marital Status	
Married	6
Widowed	4
Single	2
Living arrangements	
With family	10
Alone	2
Number of years since diagnosis (mean ± SD)	6 years ± 4.43 years

5.1. Constant Comparison Analysis. The three specific subthemes identified were (a) *adjusting physically to COPD*, (b) *using COPD self-management skills to cope physically*, and (c) *coming to terms with COPD and the lifestyle*. Table 2 summarizes the overall theme and the associated subthemes present within the focus group data.

5.1.1. Surviving and Living Well with COPD. Almost all focus group participants spoke about the inherent difficulties living life while trying to manage symptoms caused by COPD. A variety of health problems were discussed, particularly with regards to patient difficulty balancing their lives with disease management. Two participants explicitly reported symptoms such as congestion, shortness of breath, difficulty coughing, sinus trouble, and wheezing. The majority of patients substantiated these symptom claims as being common. Patients indicated difficulty identifying coping strategies which could ameliorate these specific symptoms.

5.1.2. Adjusting Physically to COPD. Physical adjustments to symptoms caused by COPD were reported by almost all members of the focus groups. Specifically, patients discussed their need to reduce the amount of movement that they engaged in from day to day. These problematic movements included basic activities of daily living such as: walking around the house, up and down stairs, and outside to take out the garbage. Participants also reported difficulty simply bending over and standing up straight without losing their breath. Because of these basic physical limitations, participants reported drastically reducing their overall activity levels:

Table 2: Theme and subthemes for data and associated codes.

Theme	Subthemes	Codes
Surviving and living well with COPD	- Adjusting physically to COPD	(i) Reduction in movement (ii) Inability to carry out activities of daily living (iii) Purposeful action (iv) Learning curve for limiting shortness of breath
	- COPD self-management: adjusting physically	(v) Medication management (vi) Limited behavioral modifications (vii) Smoking cessation difficulty (viii) Beliefs about origin of disease
	- Coming to terms with COPD and the lifestyle	(ix) Need for disease compliant lifestyle (x) Interest in attaining predisease quality of life (xi) Acknowledgement of progressive disease course

> "Everything I do I am out of breath and out of air. I find that it's sometimes worse than other times. I feel as if I have poor blood circulation to my legs as well, which makes me less wanting to walk around too much" (F2 P2 #1).

> "Walking? I can't really walk too far at all now" (F1 P2 #3).

> "If I am doing something, anything, and I seem to get real short of breath, then I just cut back. In fact, if you hold your breath a couple seconds longer than you should, then you have to try and catch your breath again" (F2 P1 #2).

> "Every time I straighten up, I feel out of breath, even after I do something simple" (F2 P1 #9; F2 P1 #2; F2 P2 #1).

> "Simply put, I am disabled" (F2 P1 #1).

In addition, female members of the focus groups talked about their difficulty performing daily cleaning chores around the house:

> "Work is a lot harder for me now, specifically cooking and cleaning. I just can't cook and clean the way that I used to because when I try to do so, I lose my breath" (F1 P3 #2).

> "For me, being a woman, I am finding that it is hard to sweep the floor. I have problems getting enough air in me when I'm doing it. When I bend down and dust to take care of the house, and I walk from room to room, and it just is so hard" (F2 P2 #1).

> "The dust in the house and animal hair gives me problems as well. Using the Pine Sol and bleach when I am cleaning sometimes gives me an attack. The Lysol spray makes me cough" (F2 P1 #2).

Because of the difficulty patients reported accomplishing their activities of daily living, some noted the need to purposively plan how they went about moving. Patients noted the need to think about what they were going to do before they actually did it. In addition, they also felt the need to act in a delayed, deliberate manner to ensure that their actions did not result in shortness of breath. When patients neglected to engage in this thoughtful process, they inadvertently accelerated their movements, and brought on shortness of breath which was unanticipated and prolonged. These exacerbations occurred when patients attempted to do the most fundamental of tasks.

5.1.3. COPD Self-Management: Adjusting Physically. Patients reported a widespread interest in wanting to learn more about COPD self-management strategies which could improve physical symptoms. While some patients reported engaging in some activities to self-manage COPD, others reported not knowing anything about what to do in terms of disease self-management. This was primarily because, for these patients, COPD was a newly encountered disease. For example, two patients expressed concerns about being unsure as to what could be done to improve the physical symptoms of COPD:

> "I don't really know how to start asking questions. I don't know what I could do or what I could take to improve the situation. I didn't want to start trying different things like over the counter stuff to get pressure off my chest or get rid of the mucus. Also, I was scared that taking it would do more harm than good" (F2 P1 #1).

> "I actually just found out that I had COPD. I wonder if the disease ever goes away? I don't know what I could do to help it or anything. Since I was just diagnosed, I am waiting on receiving information and then I can start to help treat myself. I see on TV that you are supposed to take longer walks and dance. I haven't tried any of those activities yet though" (F2 P2 #1).

Patients who had been living with COPD longer reported being better able to self-manage their disease; moreover, any lack of COPD self-management knowledge was related to the relative exposure that patients had dealing with COPD. Because of the variability within this sample in terms of years since diagnosis, this variation in COPD self-management knowledge was to be expected. The comments offered by the focus group seemed to support a continuum of patient knowledge, ranging from little to no knowledge (e.g., reflected by the comments above) to specific knowledge about ways to help manage disease-related symptoms. In particular, patients reported the regimented use of medication. All patients who had been dealing with COPD for a number of years reported feeling extremely confident in knowing how and when to use their prescribed medications:

> "I think we all use medication and know how to use the medications. We feel well informed about how to use our medications, whether it be inhalers, nebulizers, or decongestant pills. We always have our pills and medications nearby" (F2 P1 #2).

> "I can't sleep at night unless I have my mask on at night, so I have to know how to put that on" (F1 P3 #2).

In addition to medication management, patients noted the value of rest throughout the day and getting plenty of sleep at night. Apart from getting enough rest, however, patients reported a lack of knowledge and skills regarding self-management strategies which did not include taking their prescribed medication(s). Of considerable note was the absence of any patients practicing breathing exercises or controlled coughing, or using any specific relaxation techniques or energy conservation strategies. This was primarily because they had never been exposed to any seminars or informational resources which showed them how to perform these skills. It was interesting to note that patients were very inquisitive about types of activities or lifestyle changes that they could partake in to help reduce COPD symptoms. Patients seemed very interested when the conversation transitioned from focusing on medication management to focusing more on other new self-management strategies. Additionally, focus group participants raised certain questions and addressed specific learning needs related to COPD self-management. These comments included:

> "Is there a certain type of food that you eat that has an effect on your breathing?" (F2 P1 #2).

> "I want to learn more about exercise, because I'd like to walk more effectively" (F2 P2 #9).

> "I want to learn more about relaxation, so I can stay more relaxed. I feel very comfortable saying so too" (F1 P6 #5).

> "I want to be active. I want to do what I have to do to keep going" (F2 P1 #2).

Many patients remarked about how they had been encouraged to quit smoking but were unable to due to so. The reasons for being unable to quit ranged from cigarettes being too addictive to the excess expense of smoking cessation aids. Even though smoking cessation was regarded as extremely difficult, patients noted an expressed desire to "kick" the habit. This desire was motivated by patients associating with peers who had successfully stopped smoking.

5.1.4. Coming to Terms with COPD and the Lifestyle. This subtheme reflected (a) how patients rationalize their COPD diagnosis and (b) how they describe the lifestyle prompted by COPD. Surprisingly, patients had various different beliefs regarding the origin of their affliction:

> "I think that my diagnosis has something to do with being around fumes when I was working. It's either because of that or some of the stuff I used to do as a youngster" (F2 P1 #1).

> "I never had problems until I moved down south, when I got chronic bronchitis" (F2 P2 #1).

> "I didn't know why I had the disease. I never smoke, never drank. My ex-husband did, smoke, however. I didn't think I'd get the disease though, because we had been divorced since 1974" (F1 P6 #1).

Almost all of the patients in the focus groups acknowledged a need to listen to their doctor's advice regarding the self-care of COPD. Although some patients noted the initial tendency to resist doctors' orders when first diagnosed with COPD, most patients reported succumbing to the idea of a "disease-compliant" lifestyle. Patients began to realize that for life to be good, it would have to be different. Most focus group participants noted that they never regretted deciding to follow their doctor's advice.

While patients reported feeling annoyed by the deleterious impact that COPD had on their life satisfaction, they were cognizant that COPD is progressive and can get worse. Furthermore, they recognized through observing others that COPD can be extremely debilitating. Because of this, patients reported wanting to do everything they could to maintain their quality of life at a level superior to those whom they've observed to be far more affected by the disease:

> "I know this [COPD] is not death though. It just works on your nerves and changes your whole lifestyle. Some people are a lot worse than me though. I just want every drop of information I can get about this thing" [COPD] (F2 P2 #1).

> "It's really a day to day kind of disease. Now tomorrow I might try to do more, because it might be a better day tomorrow. I think that trying to do exercises might help expand my lungs, so I'll try to do more on days when I feel good" (F2 P1 #2).

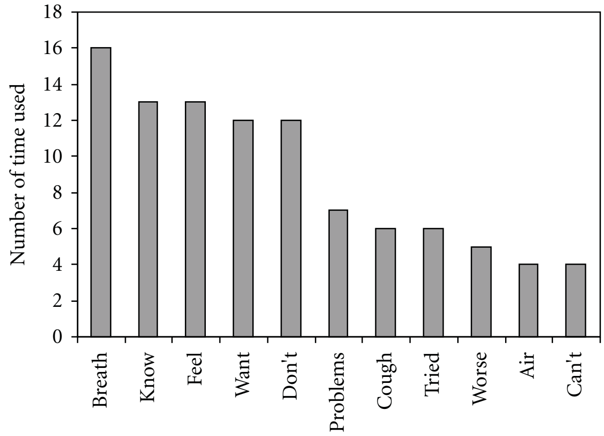

Figure 1: Most frequently used words during focus groups.

5.2. Classical Content Analysis. To complement the results gleaned from the constant comparison analysis, a classical content analysis procedure was employed. After all of the data were coded (i.e., units of data were identified and classified into systematic categories that distinguished unique data properties), it was determined how many times each code was utilized. The most frequently broached concepts included: the inability of patients to carry out activities of daily living, a lack of knowledge regarding COPD self-management behavior modification strategies, and the differential learning curve for managing shortness of breath. Participants also frequently discussed the idea of not moving in excess for fear of breathlessness. Patients reported less frequently discussing the need for purposeful living, which revealed that their current lifestyles were not currently conducive to limiting dyspnea exacerbations.

Figure 1 presents a chart that compares the frequency of the most commonly identified codes within the focus group data. While there existed some variability in the number of times each code was utilized, there was consensus regarding which subthemes (represented via codes) were most prevalent within the data. All of the frequently used codes were used to identify two of the subthemes identified in the present data. These commonly identified codes contributed to the makeup of two related subthemes: (a) *adjusting physically to COPD* and (b) *using COPD self-management to adjust physically to the disease*.

5.3. Word Count. Finally, a word count method was used to quantify the number of times a specific word was spoken during each of the focus group interviews. The word count was implemented on the final transcript using QSR International's NVivo 7.0 qualitative data analysis software program. This software enabled the seamless identification of word patterns present throughout the qualitative data [53]. The most commonly used words within the transcript were: *breath, know, feel, want,* and *don't*, with *breath* being the most commonly cited word. Patients overwhelmingly mentioned the word *breath* during the course of the focus groups, which revealed how important the maintenance of

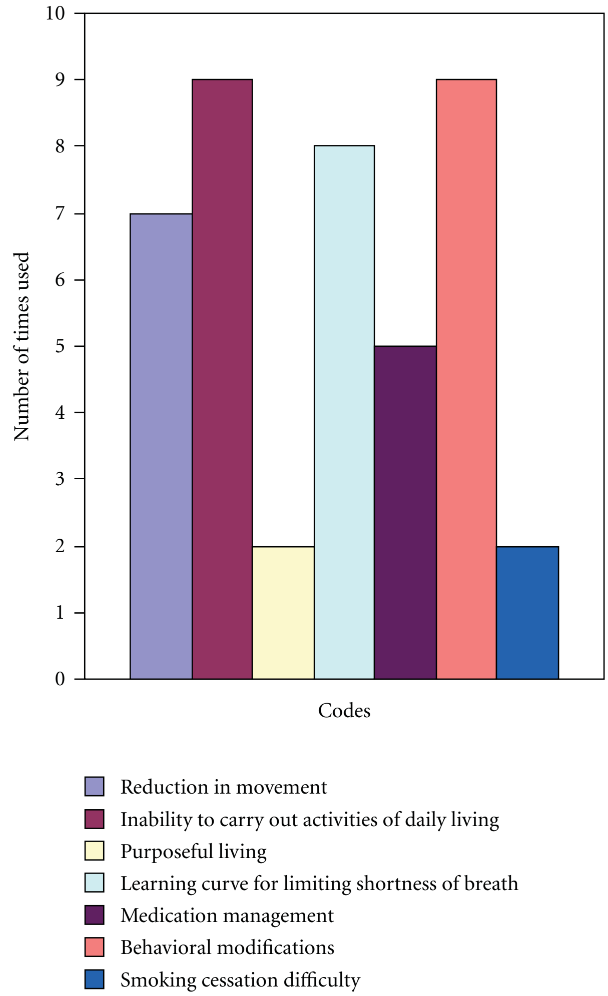

Figure 2: Results from classical content analysis.

breath was to both their quality of life and overall perception of COPD. The participants had very strong *feelings* related to *wanting* their shortness of *breath* to be limited. Patients were adamant in their desire to receive any *knowledge* that could help limit the onset of dyspnea exacerbations. Figure 2 depicts the frequency of the most commonly spoken words.

Lesser used, but frequently mentioned words such as *problems, tried, worse,* and *can't* were also of note. Focus group participants reported having *tried* to cope with the numerous *problems* caused by COPD; but, more often than not, patients reported their symptoms as becoming demonstrably *worse* no matter what they tried to do. What is more, patients could not readily identify multiple ways to limit the onset of shortness of breath. It was interesting to note the omnipresence of words such as *want* and *don't* as compared to *tried* and *can't*. The differential use of these specific words may provide unique insight into how patients view surviving and living life with COPD. While most all patients reported an expressed desire to *want* to do something to self-manage COPD, the efforts prompted by this desire did not (*don't*) necessarily result in the health outcomes they were looking for. Thus, the focus group participants seldom reported that they *tried* to actively limit their shortness of breath. Primarily, this was because patients *can't* successfully engage in activities (other than taking medications), which actually helped reduce their dyspnea. In light of this, most patients felt reduced to simply taking their medications, with little guidance regarding other options for COPD self-management.

6. DVD Development

RVision Corporation [55] developed a library of education and exercise rehabilitation content for home use by patients with COPD. These three COPD self-management educational segments cover almost 70 instructional topics. Topics include pursed lip and diaphragmatic breathing techniques, aerobics and conditioning, infection management/treatment, medication management, smoking cessation, aero chamber and bronchodilator use, energy conservation, relaxation techniques, cough controlling, nutrition, weight management, and walking for exercise. Previous work has shown that patient use of this specific content can result in improvements of quality of life, fatigue, and exercise compliance [38]. Table 3 lists content areas covered within each of the 3 segments. These segments run for approximately 1 hour, and 30 minutes in length in total. To condense these segments and target them to the learning needs of the participants in this study, video editing technology was used to compress the relevant patient education topics (identified during the qualitative data analysis) into a single interval of approximately 30 minutes. Each topical segment was placed in a unique chapter on each DVD. This was done to allow patients to specifically choose the segments they wanted to watch, without being forced to watch the entire DVD at each sitting. This was also done in recognition that there was going to be variability in the types of topics that patients might already be familiar with. Within each segment, sources of efficacy information included performance mastery techniques, role modeling, physiological coping, and verbal persuasion [56].

7. Discussion

In sum, the self-management experiences of COPD patients in these focus groups were limited to taking prescribed medications and reducing movement and activity. Patients reported widespread confidence with regards to managing and using prescribed medications to treat COPD symptoms, and they also perceived that getting plenty of rest could reduce their shortness of breath. However, the focus group participants did not realize the importance of practicing other COPD self-management skills and behaviors. By and large, patients reported a lack of knowledge and skill development related to alternative rehabilitative activities such as controlled breathing and coughing, stress reduction, smoking cessation, nutrition, and paced walking/activity. Furthermore, the focus group participants expressed an interest in learning more about these and other novel topics, which have universally been identified as staples

Table 3: Content covered within 3 RVision DVD segments.

Content	Running Time
COPD Education Segment #1	
Pursed Lip Breathing	55 seconds
Diaphragmatic Breathing	1 minute, 2 seconds
Energy Conservation	1 minute, 34 seconds
Introduction to Relaxation Techniques	35 seconds
Deep Breathing	22 seconds
Total Muscle Relaxation	1 minute, 39 seconds
Visual Imagery	21 seconds
Helpful Hints for Relaxation	24 seconds
Avoiding Stress	23 seconds
Panic Control Breathing	47 seconds
Bathing and Showering	1 minute, 8 seconds
Grooming	32 seconds
Dressing	44 seconds
Aerobics and Conditioning Introduction	23 seconds
Walking for Exercise	2 minutes, 37 seconds
Breath Saver Tips	37 seconds
Lifting and Breathing	15 seconds
Bending and Breathing	24 seconds
Going Up Stairs	39 seconds
Infection Control	1 minute, 41 seconds
Infection Detection	1 minute, 1 seconds
Infection Treatment	59 seconds
When to Call Doctor	1 minute, 17 seconds
COPD Education Segment #2	
Medication Introduction	30 seconds
Bronchodilators	36 seconds
Antibiotics	44 seconds
Metered Dose Inhalers	4 minutes, 10 seconds
Proper Use of Inhaler	41 seconds
Digoxin	33 seconds
Corticosteriods	42 seconds
Side Effects of Prednisone	1 minute, 5 seconds
Controlling your Cough	47 seconds
Nutrition	2 minutes, 39 seconds
Tips for Good Nutrition	6 minutes, 15 seconds
Increasing Your Fluid Intake	1 minute, 29 seconds
High Potassium Foods	1 minute, 2 seconds
Diet Hints	49 seconds
Weight Management	1 minute, 12 seconds
Eating Out	48 seconds
Avoid Constipation	34 seconds
COPD Education Segment #3	
Home Bicycle Program	1 minute, 58 seconds
House Keeping	1 minute, 11 seconds
Travel	1 minute, 55 seconds
Intimate Relations	2 minutes, 19 seconds
Smoking Cessation	1 minute, 22 seconds

Table 4: Final segments included on DVD (edited).

Content	Running Time
Introduction	49 seconds
Pursed Lip Breathing	55 seconds
Diaphragmatic Breathing	1 minute, 2 seconds
Energy Conservation	1 minute, 34 seconds
Introduction to Relaxation Techniques	35 seconds
Deep Breathing	22 seconds
Total Muscle Relaxation	1 minute, 39 seconds
Visual Imagery	21 seconds
Helpful Hints for Relaxation	24 seconds
Avoiding Stress	23 seconds
Panic Control Breathing	47 seconds
Aerobics and Conditioning Introduction	23 seconds
Walking for Exercise	2 minutes, 37 seconds
Lifting and Breathing	15 seconds
Bending and Breathing	24 seconds
Infection Control	1 minute, 41 seconds
Infection Detection	1 minute, 1 seconds
Infection Treatment	59 seconds
When to Call Doctor	1 minute, 17 seconds
Controlling your Cough	47 seconds
Nutrition	2 minutes, 39 seconds
Increasing Your Fluid Intake	1 minute, 29 seconds
House Keeping	1 minute, 11 seconds
Smoking Cessation	1 minute, 22 seconds
Conclusion	22 seconds
Total (approximate)	34 minutes, 18 seconds

within COPD self-management regimens [10]. It should be noted here that the social characteristics of this particular community may limit the generalizability of these particular educational needs. However, the findings from this study may generalize to communities which possess similar shared characteristics. In this primarily rural community, it can be surmised that needs identified from these focus groups can potentially be applied to other COPD patient populations represented by relatively equal proportions of African American and Caucasians who are living at or below regional poverty lines with a low socioeconomic status.

Given the learning needs identified earlier, the low educational levels of many of the patients in the sample, and the variability in terms of patient time spent coping with COPD, careful attention was paid to developing the DVD instructional tool based on patient feedback obtained during this exploratory study. It was imperative to only include segments that were comprehensible, to the point and clear. Segments which contained relatively novel COPD self-management education (determined based on input from patients) were selected for inclusion, while segments deemed irrelevant were not included. The edited DVD was not intended to bombard patients with an excess of information that they could not remember and use; rather, it was developed in hopes of keeping patients' interest by only including information that they would find to be applicable to their disease self-management efforts.

For example, there were no segments included on medication management, because most patients felt comfortable using their medications, and these segments tended to describe specific prescription medication terminology, which may have confused patients who did not explicitly remember the names of the medications that they were currently taking. Given that the majority of patients in the focus groups had been diagnosed for many years (Mean = 6 years; SD = 4.43 years), they professed being familiar with the medications they used regularly to management their disease. Had the focus groups or patient sample been composed of those more recently diagnosed with COPD, however, it would have been prudent to include information on prescription management and adherence to help assist patients in adapting to their new disease status. After taking into account input from the Medical Director of the clinic where the patients were treated, the DVD clips were edited and placed on an original disc. Table 4 presents the content areas included on the edited DVD and the running time for each segment.

The total run time for the entire edited DVD was approximately 34 minutes and 18 seconds. It was used in a study [57] to determine optimal self-management education strategies for COPD patients. Patients provided with a DVD reported watching the targeted segments multiple times (Mean = 2.58, SD = 1.81), perhaps because of the control they had over the implementation of the DVD player used to transmit the self-management education. Moreover, using DVD technology as the technological modality for this intervention gave COPD patients the greatest opportunity for empowerment over persistent shortness of breath which characterizes their disease. Patients could view the educational material in the convenience of their own home, using a technology they were familiar with, at their own discretion. Given the geographic and socioeconomic characteristics of this sample of COPD patients, the overarching instructional strategy supported limited interpersonal interaction with patients. Thus, a *distance education* method served as the primary means of instruction. For the purpose of this project, distance education can be defined best by Moore [58] as, "all arrangements for providing instruction through…electronic communications to people engaged in planned learning in a place or time different from that of the instructor or instructors" (p. xv).

In future dissemination studies using the targeted DVD within the distance learning milieu, various other telecommunications vehicles may be integrated into self-management education for rural patients with COPD. For example, the multimedia content reformatted for this project (i.e., to coincide with patient self-management education needs) has been posted on the internet by way of YouTube broadcasting using the feed managed by the proprietor of RVision Corporation: http://www.youtube.com/watch?v=pte_GGQb1_4. The authors posit that these types of interactive, media sharing URLs will allow COPD patients to contribute both video and text-based responses, comments and concerns as regards the self-management tutorials streamed over the internet. An added benefit of using the YouTube application is that patients subscribing to the feed will be afforded the opportunity to view related videos within the preexisting library of all health education segments produced by RVision Corporation. For the multitude of COPD patients that suffer from other, comorbid chronic conditions, the access to these libraries could prove to be an extremely valuable resource. RVision Corporation educational content for various diseases and disorders (including COPD) is commercially available and distributed by Health Ix via their website: http://www.healthix.com/. Each video clip posted for telemedical purposes could be dispensed using a unique host URL link.

This integration of video-based education in an open access web environment (e.g., YouTube) can provide a forum for patients to share their experiences attempting to cope with disease-related issues within a virtually networked community. For rural patients who have difficulty commuting to a common, localized site for health services and support, this portal containing instructional multimedia material is ideal. This converged approach to congregating patients and providers in a user environment amenable to patient/provider feedback can enable the site administrator to continually meet patient needs for self-management education. In addition, the administrator has the luxury of managing and optimizing a single network to transmit both audio-visual education and patient feedback asynchronously over the internet on a common system. This technologically-mediated strategy would reduce rural patients' need to travel and deliver the educational content directly to patients at their place of residence in the same vein as the DVD, but with the added networking capacity.

Access to this host URL could also be granted to certified medical personnel of rural health clinics to better assimilate the DVD content with tailored medical advice provided both through audio-visual and text-based responses. Special attention must be paid to ensuring that patient confidentiality is not breached when sharing medical information within a public domain forum on the internet. An encrypted web portal with VOIP software applications (e.g., Skype, Google Talk, Cisco IP Communicator, etc.) enabling two-way voice communication over the internet could assuage concerns regarding the unauthorized transmission of patient health information.

At this point, it should be noted that this future work will only become realized should pending financial stimulus be allocated to rural health networks for greater broadband access to the internet. Recent initiatives in the United States have suggested that this enhanced, internet access for rural America is forthcoming for these underserved areas. Furthermore, future researchers using this proposed converged networking approach to technologically-mediated disease self-management education should be confident that patients/providers are prepared with instruction and training to use the internet and all related applications. Without patient/provider access and efficacy with regard to internet/software navigation, the fruits of the internet as a telemedicine application can be very limited. It is suggested that such attempts be formatively pilot tested in areas of higher socioeconomic status, before broad-based implementation in rural, underserved areas is attempted. The aforementioned mobile COPD self-management education service, in a converged networking environment, would be especially useful in a technologically capable sample of rural COPD patients, because the majority of focus group participants expressed difficulty transporting themselves from their homes to their rural health clinic and often could only do so with assistance from friends and family members. Patient populations living in urban regions may not be affected by this geographic barrier; thus, the proposed intervention may be less appropriate in areas with a dense populous.

Focus group data proved extremely useful to identify and confirm patients' learning needs. Engaging in such formative qualitative inquiries may prove invaluable when attempting to meet the self-management education needs of diverse patients who are difficult to reach. It would stand to reason that results from this study suggest that the prospect of using self-management education DVD content could potentially stimulate high utilization rates among rural COPD patients, which could overcome significant barriers relative to widespread distribution of COPD self-management techniques. By disseminating targeted educational technology resources to underserved populations, health educators may be able to broaden the reach of COPD self-management messages and help patients feel more satisfied with the patient education they receive.

Appendices

A. Focus Group Rubric

A.1. Introduction. Good morning/afternoon, and welcome to our session. Thank you for taking the time to join our discussion of COPD patient education needs and self-care. My name is Michael Stellefson, and I am a doctoral student at Texas A&M University in College Station, Texas, and I am studying patient education needs for COPD self-management. Today I'd like to hear from you about how you view caring for yourself and your COPD and what types of topics you would like to learn more about pertaining to how you can care for your disease. You were selected for this discussion because you all have a diagnosis of COPD and you are treated here at Choctaw Urgent Care. I am very interested in your views of your disease and your experiences trying to manage your breathing.

Today we basically want to learn from you about how you live with COPD and what types of disease self-management activities you'd like to learn more about. Please feel free to share your point of view whatever it may be, as there are no wrong answers to my questions. Please try to speak one at a time and speak up whenever you want to add something to the discussion. I am tape recording our conversations so that I don't miss any of your comments. We will be on a first name basis, and your names will not be attached to any of your comments to ensure your confidentiality.

My role here is to ask questions and listen. I will be asking about 10 total questions, and I'll move the discussion from one question to the next. As you talk and discuss issues, I will be taking notes about what you are sharing, so even if I'm writing, please continue with your comments, as I am trying to listen to everything you are saying. Please share as much as you can, but leave time for everyone to have the opportunity to share their thoughts and feelings. Also, please feel free to talk with one another. I've placed name cards on the table in front of you so that we can all remember each other's names during the discussion. We'll be done by (—), and I'll leave a little time at the end so you can finish the surveys in front of you. So to start…

A.2. Questions

(1) Think back and tell us when you were diagnosed with COPD, and how long you have been dealing with health problems because of your disease?

(2) What types of daily activities do you wish that you could do but don't feel able to do anymore because of having COPD?

(3) When you think about trying to take care of yourself with your disease, what types of activities do you think about doing?

(4) Of these activities, what do you do, yourself, do to help take care of your disease (i.e., things that you do so you don't feel short of breath or ill)? What allows you to do these activities?

(5) What new and/or different activities did you maybe try to do to manage your disease but maybe did not feel comfortable continuing because of discomfort or difficulty? Can you think of any specific barriers that prevent you from trying to take care of yourself?

(6) What questions do you have regarding what you can do to help limit the problems that you experience because of COPD?

(7) Of all of these activities that we just discussed, what type of self-treatment activity do you consider most important?

(8) What would like to learn more about in terms of taking care of yourself with your disease? What advice could you give someone who was trying to determine what to teach a patient with COPD?

B. Member Check

(1) How well does this summary capture what we discussed today? Does what I said sound accurate?

(2) Is there anything that we did not talk about today regarding how you take care of your COPD that you would like to mention?

Acknowledgments

This project is supported by Grant #R36HS017387 from the Agency for Healthcare Research and Quality (AHRQ). The content is solely the responsibility of the authors and does not necessarily represent the official views of the AHRQ. The author wishes to thank Charles P. Spickert, MPH, President and CEO of RVision Corporation; Dr. Katherine Hensleigh, MD, Medical Director of Choctaw Urgent Care; and Ms. Wendy Ridgeway, Certified Nursing Assistant at Choctaw Urgent Care, for their steadfast support of this project. In addition, the author would also like to recognize Drs. James M. Eddy, Danny R. Ballard, and Rafael Lara-Alecio, for their guidance and assistance preparing this manuscript.

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Hindawi Publishing Corporation
International Journal of Telemedicine and Applications
Volume 2010, Article ID 357156, 7 pages
doi:10.1155/2010/357156

Research Article

Tile-Ippokratis: The Experience of an Ehealth Platform for the Provision of Health Care Services in the Island of Chios and Cyprus

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Received 2 November 2009; Revised 2 May 2010; Accepted 19 July 2010

Academic Editor: Tasos Dagiuklas

Tile-Ippokratis proposed an integrated platform for the provision of low-cost ehealth services to citizens in southeast Mediterranean area (Island of Chios and Cyprus). The aim of the paper is to present the architecture, the design, and the evaluation results of this platform. The platform based on already evaluated state-of-the-art mobile ehealth systems and using wireless and terrestrial telecommunication networks is able to provide the following health care services: (i) telecollaboration and teleconsultation services between health care personnel and between health care personnel and patients and (ii) ehealth services for "at risk" citizens such as elderly and patients with chronic diseases (Island of Chios) and postsurgery patients (Cyprus). The ehealth systems supported capabilities for vital signal measurements (ECG 1 lead, SPO2, HR, BP, weight, and temperature), an Electronic Patient Record (EPR) infrastructure, and video conference, along with communication gateways for data transmission over ADSL, GPRS, and WLAN networks.

1. Introduction

Ehealth is an umbrella term which refers to the use of information and communication technologies (ICTs) for the provision of health services from distance. Ehealth, distinguished into eCare, eLearning, eSurveillance, and eGoverment/eAdministration [1], is one of the most rapidly growing areas of health. According to a global survey of the World Health Organization (WHO) there is a significant demand for the provision of generic tools to support the clinical (elearning tools, access to digital libraries, databases to support evidence-based medicine, telemedical systems, remote diagnostic systems, electronic patient records, decision support systems, etc.) and administrative (e.g., financial support systems, patient referral systems, etc.) functions of health care services in WHO member states [2]. The above is in line with the latest attempts, which have shown that the use of ICT for the provision of healthcare services across geographic, temporal, social, and cultural barriers gave a great promise to help people in isolated and remote regions to gain access in health care services [3].

The evolution on ehealth systems supported by advanced algorithms, high performance computers, sensors, monitoring devices, and telecommunication networks permits the provision of good quality of medical care even to remote/isolated regions, the information exchange, and the distribution of medical knowledge among health care professionals [3].

Ehealth applications have been successfully used for the provision of emergency ehealth in understaffed areas like, among others, rural health centers [4, 5] as well as for home monitoring and home care [6, 7], whenever is needed. Recent studies have shown that the home monitoring of elderly patients, as well as patients with chronic diseases, increases the individual's comfort, enhances quality of life, and encourages the patient empowerment while it reduces the number of needless transfers at hospitals and the cost of provided health care services [7–9].

Furthermore several projects deal with elderly chronic disease management as CONFIDENCE [10], ATTENTIANE [11], ENABLE [12], and K4Care [13].

This paper presents the architecture of the Tile-Ippokratis ehealth platform. The platform covers a wide range of services:

(i) support the collaboration and consultation between remote located health care personnel,

(ii) enable the electronic monitoring of "at risk" citizens, elderly, and patients with chronic diseases, in the area of Island of Chios,

(iii) home telemonitoring of post-surgery patients who had been provided intensive care medicine in the Intensive Care Unit of the Nicosia General Hospital; these patients were having Home Ventilation Care within their residents.

The main objectives of the project are considering:

(i) the collaboration between doctors and citizens located in Greece and Cyprus with different health care systems, different technology infrastructure, and different needs, in order to enhance the quality of health care services in the region South Mediterranean,

(ii) the improvement of the self-management skills of those patients with minimum ICT skills (the ehealth platform and their electronic personal record could be accessed by them through a web browser),

(iii) the efficient monitoring and health management of chronic and post-surgery patients by their doctors and the early response to emergency incidents using low-cost state-of-the-art web-based technology,

(iv) the evaluation of the usability and acceptability of the proposed ehealth services in the pilot areas.

The platform, which had been developed during the Interreg IIIA "Tile-Ippokratis" project: An INTEgrated pilot ehealth-platform for enhancing health care provision between Greece and Cyprus, has been tested and validated in the pilot sites in Greece and Cyprus (Figure 1). The platform and the provided services have been assessed by patients and physicians in the aforesaid sites.

The platform (Server Software, EPR, Web Viewer-enabling Internet access to patient measurements) has been installed within the premises of the National Center for Scientific Research, "Demokritos".

In the Island of Chios the platform has been used by the Skylitsio General Hospital of Chios and the rural medical peripheral health centers residing in Chios Prefecture Municipalities of Volysos, Kardamyla, Oinouses and Pyrgi supporting elderly citizens and patients with chronic diseases. The patients were receiving support in the rural health centres.

In Cyprus the platform has been used by the Intensive Care Unit of the Nicosia General Hospital supporting post-surgery patients in the municipalities of Nicosia, Larnaca and Limassol. The patients were receiving support in their own homes.

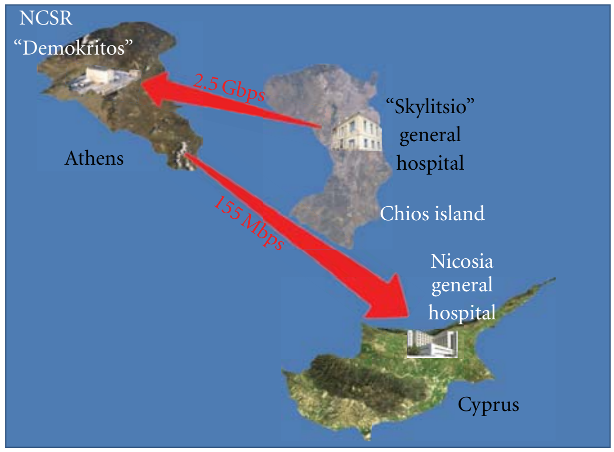

Figure 1: Tile-Ippokratis pilot sites.

A summary of the various services provided per pilot site and transmitted data is presented in Table 1.

The paper describes the Tile-Ippokratis architecture, the design of the entire platform, the provided services, the used systems, and the platform infrastructure (Section 2) and presents the protocol of the trials (Section 3). In Section 4, the evaluation results of the validation phase are discussed while the conclusions are presented in Section 5.

2. Platform Description

The description of the platform is divided into three parts. The first part describes the teleconsultation systems and the patients' peripheral systems that entail the acquisition of the patients' biosignals and their transmission to the central database server, the second part describes the remote centralized database itself, and the third part describes the network technology selected for the uploading of the data to the database.

2.1. Teleconsultation Systems and Patients' Peripheral Systems. The Tile-Ippokratis platform provides a series of services, which have been supplied through the combined use of already evaluated systems (off the self-systems as well as systems coming out of EU-funded projects) as presented in the following paragraphs.

(1) *Teleconsultation Systems.* The teleconsultation services have been mainly provided by the Wavelet-based INteractive Video Communication System (WinVicos). WinVicos is a high-end, interactive video conference system providing real-time video, still images, and audio transmission [14]. The system has been designed mainly for medical applications, like intraoperative teleconsultation, in various EU-funded projects. WinVicos supports communications via satellite, Local Area Network (LAN), Internet, ATM, xDSL, and so forth.

Table 1: Services provided per pilot site.

Connected end-points	Services	Data transferred between end-points
NCSR (server)	EPR, Web services	Incident data: personal info, contacts, medical info (diseases, medication), medical data (vital signs)
Skylitsio General Hospital (monitoring station)	Teleconsultation, ehealth	Medical data (vital signs), images
Rural medical peripheral health centers residing in Chios Prefecture Municipalities of Volysos, Kardamyla, Oinousses, and Pyrgi “at risk” citizen (client)	Teleconsultation, ehealth	Incident data: personal info, contacts, medical info (diseases, medication), medical data (vital signs), real-time video conference
Intensive Care Unit of the Nicosia General Hospital (monitoring station) postsurgery patients in the municipalities of Nicosia, Larnaca, and Limassol (client)	Teleconsultation, ehealth	Incident data: personal info, contacts, medical info (diseases, medication), medical data (vital signs), real-time video conference

The teleconferencing scenario was realised with the use of a web camera connected to the computer, a set of speakers, and a microphone for the audio signal and the WinVicos software. In some cases commercially available teleconferencing software such as adobe connect (http://www.adobe.com/products/acrobatconnectpro/) has been adopted in those cases where the patients had to have routine teleconferencing sessions with their carers (Cyprus pilot). A frame rate of at least 25 fps at a resolution of 640×480 pixels was a preferred one for the real-time teleconferencing sessions.

Teleconferencing has been introduced for two reasons: to improve the patients’ confidence to the treatment creating a feeling of safety for the patient and to support the collaboration and consultation between remote located health care personnel.

(2) *Patients’ Peripheral Systems.* For the ehealth services the following low-cost systems have been used for the provision of telemedical services in Chios Island and Cyprus. It consists of the following components:

(i) personal computer (PC) or laptop,

(ii) biosignal acquisition module (Wrist ClinicTM (http://www.telcomed.ie/allinone.html)) which is responsible for biosignal collection (Figure 2); more specifically, this lightweight and mobile module is able to collect, record, store, and wirelessly transmit 1 lead ECG, SpO2, HR, BP, and TEMP up to 250 m; the device can store data if there is no connection,

(iii) fully wireless weight scale (http://www.telcomed.ie/scale.html) which allows untethered operation (no communication or power cords); the patient can use the weight scale anywhere within coverage area (250 m communication range in open space),

(iv) software (client) for communication with the central database (Cyprus pilot),

(v) application (client) for medical monitoring in public environments allowing multiple patients to use a single device (Chios pilot),

(vi) two-way radio USB-based communication device (automatic data accumulation and transmission) which connects via ordinary internet connection; the device has 200 m communication range (open space), uses reliable data communication protocol, and has a unique digital ID for system identification. The data are transmitted from the monitoring devices to the home computer using a wireless connection (WiFi).

There is wireless connection between USB device (onboard the PC), the biosignal acquisition module, and the wireless weight scale. The selected data are stored to the PC, while an asymmetric digital subscriber line (ADSL) internet line is used for uploading data from the PC or laptop to the data base.

2.2. Remote Centralized Database. The EPR has been stored in an SQL-type database. The EPR information included patient details, medical info (diseases, medication), and the medical data (vital signs) acquired from the monitoring devices deployed. The data were structured in an efficient way. The medical and care personnel were able to utilize a standard web browser to login on a webpage to view a patient’s record and search for readings that fall within a given range or from a specific time and date. This ability assisted medical personnel to reassure themselves about patient’s condition providing the patients with an extra feeling of safety.

2.3. Network Description. The broadband telecommunication network integrated two types of networks, terrestrial and wireless. The network has been based on nodes of research institutes (National Center for Scientific Research “Demokritos”—NCSR), hospitals (Nikosia General Hospital and Chios Skylitsio Hospital), and the four rural peripheral medical centers in Island of Chios. Each node is connected to its appropriate router via an Ethernet link running TCP/IP protocol. The network provided broadband coverage to all the partners in Greece and Cyprus thus ensuring communication between different and remote parties allowing for data

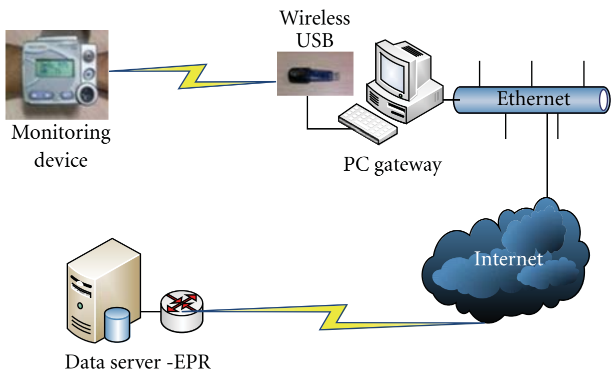

Figure 2: The system operation process.

transmission and bidirectional communication by means of audio-visual content transmission.

Through the platform clinical data have been exchanged which were collected by distributed nodes (e.g., regions supported by low-bandwidth earth network, such as rural areas in Chios Island). The uploading of the measurements data from the patients' premises to the database have been achieved either by wireless technologies—General Packet Radio Service (GPRS) data cards for PC have been used or wired technologies—Asymmetric Digital Subscriber Line (ADSL) depending on the availability of ADSL connection. ADSL was selected to be the primary technology for use in the patients' premises as well as in the Peripheral Health Centres due to the low overall cost of usage compared to the other technologies available and the provision of high speeds which can support the teleconferencing scenario as required in the project. Depending on the availability of ADSL lines, the patients' Peripheral Health Centres were connected with speeds of 1.024 Mbps download and 512 kbps upload which were sufficient for monitoring and teleconferencing. In the case of the patient's premises, these were connected with speeds of at least 512 kbps download and 128 kbps upload which were sufficient for monitoring.

Security issues in health care information systems are of great importance. Our major objective was to allow doctors quickly access patient data when and where they needed it without compromising security. In the proposed integrated ehealth platform security, mechanisms are incorporated in order to protect the information during the transmission and storage as well as at the system level (logical access control, legitimate, and availability). For each network type an efficient security policy has been deployed, in order to protect data from unauthorized use or alteration/damage and legal issues that concern the exchange of medical data between the two countries.

The platform maintained the security of the data throughout all the communication stages, data storage, and user access to the data. More specifically the following security actions have been adopted:

(i) access control/single sign-on,

(ii) authentication,

(iii) authorization—user Access rights,

(iv) session control,

(v) activity log—audit,

(vi) data protection,

(vii) encryption—HTTPS SSL,

(viii) network firewalls,

(ix) application security—application Firewall.

3. Protocol for the Trials

During the six-month trial phase, general practitioners and specialized doctors supported the chronic and postsurgery patients from distance, minimizing routine transportation of patients from and to hospitals. The recruitment process was based on willingness, ability, and commitment of the patients referenced by medical personnel in charge. A training process was conducted concerning the use of devices and the protocol of the monitoring program. Regular followup with users by the project partners involved scheduled reassessment, reassurance of the case management program compliance, corrective actions, reinforcement of the pilot patients and medical personnel.

Particular attention has been paid to ethical issues.

(i) The respect of their privacy: an internal Consortium Agreement regulated all the operations involving them with basic rules imposing the respect of their habits, their environment, and their times.

(ii) The respect of an ethic code, ensuring a correct behavior and the respect of the patients' rhythms and attitudes. Signs of discomfort or uneasiness on the user's part during the evaluation activities have been taken into consideration.

(iii) The collaboration with their family members: people surrounding the end users have been involved in the evaluation process. The patients have been provided with information about the purpose of the research activities, duration of their participation, and which procedures are followed.

Sixteen patients suffering from chronic diseases participated in the trials in Chios Island:

(i) four hypertensive patients were monitoring their HR and BP,

(ii) four individuals with chronic pulmonary disease (chronic asthma or chronic obstructive pulmonary disease) were monitoring their SpO2 and ECG daily,

(iii) eight individuals with chronic cardiovascular disease were monitoring their ECG, BP, and weight.

According to the rural health center scenario (Island of Chios) and the protocols that have been applied by the four General practitioners of the rural health centers together with two specialized doctors in Skylitsio General Hospital, the selected patients were measuring their vital signs frequently (2-3 times per week) in the rural health centers. Although the sixteen patients were using only

Table 2: Overview of technical metrics of Tile-Ippokratis services.

	Connectivity with networks	Ease of data transmission
Home care	Low rate of failures (∼< 1%)	No problems reported
Rural health centre	Low rate of failures (∼< 1%)	No problems reported
	Quality of data transmission	Interference to other medical equipment
Home care	Excellent	None
Rural health centre	Excellent	None
	User friendliness	Wrong findings
Home care	Users satisfied, amendments asked	No wrong alarms
Rural health centre	Users satisfied, amendments asked	No wrong alarms

four sets of devices, the vital signs through a software application for medical monitoring in public environments were automatically transmitted and saved to their electronic personal records maintained by NCSR "Demokritos". These data were accessed frequently, at least once per week, by the medical personnel of the Skylitsio General Hospital of Chios, who were able to provide remote consultations. Based on the monitoring data and on the direct sight of the patient through the videoconference facilities the doctors from the Skylitsio General Hospital of Chios provided a second opinion to the local doctors of the rural health centers when needed.

Six postsurgery patients in Cyprus participated in the trials in Cyprus (home care trial) conducting daily from their home a full set of measurements: HR, SpO2, BP, 1 lead ECG, Temp, and weight where possible. In this scenario each patient owned one set of ehealth systems. The vital signs through the home gateway were automatically transferred and saved to their electronic personal records maintained by NCSR "Demokritos". The medical personnel of the intensive care unit (two specialized doctors) of the Nikosia General Hospital accessed at least once per week the Electronic Patient Records providing remote consultations where necessary. The patients were able to contact their doctors via video/audio to seek medical advice. Furthermore an admin support and medical help desk has been integrated into the service concept in Cyprus pilot to motivate the patients to adhere the planned protocol.

For the home care scenario, emergency events at home have been planned as possible to happen. The scenario concerned a patient who collects vital measurements whenever he/she does not feel well. In case abnormal situations occur and the measurements exceed set levels for a given patient, alarms triggered and doctors, family members, and emergency services automatically were notified. It has to be mentioned that during the pilot phase this scenario has been rarely conducted.

4. Platform Evaluation and Discussion

The evaluation of the Tile-Ippokratis ehealth platform has been primarily technical in order to verify that the systems can operate in reliable way and end users' oriented (using questionnaires and interviews) in order to investigate how the system can be embedded in everyday clinical practice. During the trials the users from both server and client sites were asked to evaluate the system, in order to evaluate not only the one-way use of the system but also capture the impressions of ICT-mediated interaction.

Taking into account the inherent variety in the project, Tile-Ippokratis consortium opted for an evaluation approach which collects data from a variety of sources in order to ensure the integrity and generalisability of the results. To this end, data were collected through the following methods:

(i) Technical metrics deriving from monitoring the ehealth system during the pilots,

(ii) Users' acceptance metrics collecting quantitative and qualitative data pertaining to the usability of the system and its users' overall experience.

4.1. Technical Evaluation. Tile-Ippokratis was evaluated on a number of critical technical factors which were identified as important by desk research and discussions with computer engineers and physicians. These factors guided the collection of data showing the performance of Tile-Ippokratis during its operation in the various scenarios tested during the trials; the overall results from these tests are shown in Table 2.

More specifically the first critical factor is connectivity which is defined as the capability of the ehealth system to transmit data between client and server units without any disruptions. This is the basis for the operation of any ehealth system which aims at providing continuous support to its users. Tile-Ippokratis scored high in this area having low failure rate less than 1% in the "home care" and "rural health centre" scenarios.

Ease of data transmission was the second evaluation factor. It accounts for both the ease of data transmission of biosignals and all other necessary data (e.g., video) for effective diagnosis over the network as well as the ease of data entry by users into the Tile-Ippokratis system. Given the trial results in the above-mentioned technical factor (connectivity) the outcome of ease of data transmission follows the same pattern. In the "home care" and "rural health centre" scenarios there were no problems with ease of data transmission. Data were transmitted successfully during each repetition of the trials.

The third factor quality of data transmission examines a parameter of paramount importance in telemedicine as suggested by relevant literature [15]. Data transmitted

Table 3: Perceived benefits of Tile-Ippokratis services.

		Type of users	
		Physicians	Patients
Scenario	Home care	Good alternative for avoiding frequent visits to the hospital Long term-appreciation of patient's situation—useful in cases of emergency Shifting of the location of care, out of hospitals	Increased sense of safety Avoidance of unnecessary visits to the hospital Increased sense of "always connected" with their doctors
	Rural health center	Sense of "team" work between remote located medical personnel Time savings from patients' transportation to Skylitsio General Hospital and other large hospitals Increased sense of safety because of the second opinion choice Low-cost ehealth services. One ehealth system for many patients Ensuring continuity of healthcare and patient followups	Larger number of patients own their electronic personal record Increased positive attitude against ICT technologies Promotion of behavioural modification, goal setting, prevention rather than treatment and adjusting to living with a chronic disease improving patients' feeling of safety Assist patients to self-manage their chronic condition and enhance supportive measures to promote self-management in the long term

through ehealth equipment must maintain its integrity during transmission for the receiver (usually a doctor or medical personnel) to be able to produce an informed and valid opinion on the patient's condition. In both "home care" and "rural health center" scenarios, which were examined during the same trial, there were two major types of medical data transmitted through the applied network.

(i) Numerical data which are essentially the biosignals recorded by the system (weight, 1 lead ECG, BP, HR, SpO_2, and temperature).

(ii) Video-conferencing files. These were recordings automatically captured by the video-conferencing software which could be stored for subsequent review.

According to the data recorded by the project servers, in both these cases there has been no problem with the quality of data transmitted. Data was of excellent quality, and there were no complaints from both client and server units. Given the stable connectivity among the client and server sites there were no failures in the transmission of data.

The fourth factor was interference to other medical equipments. There were no recorded problems regarding the interference of the equipment with other medical devices mainly in the rural health centers scenario. Users from both server and client units expressed a positive opinion on the interface and data entering procedures of the devices used by Tile-Ippokratis.

4.2. Evaluation of User Acceptance of the Ehealth Platform. Following the technical evaluation, a small-scale evaluation of the users' acceptance of the systems was performed. Whitten et al. [16] point out that users see the ehealth systems primarily as services provided to them and not as new technologies. Having this in mind and the fact that the success of every system relies on the user acceptance and user opinion must be taken into serious account as well. The evaluation of the users' acceptance of the systems included collection of data on perceived benefits for the services provided. Users were asked to fill in questionnaires regarding their experience with the interaction with the system. Interviewing them allowed us to clarify hidden attitudes and beliefs. Their views, from both server and client perspective, are summarised in Table 3.

The proposed platform was surprisingly welcomed by patients and carers because of its simplicity and functionality although most of the patients were not comfortable with using video communication and pc technology (especially the elderly one). The whole service has been viewed as an early warning mechanism which helps prevent frequent hospital visits. But although the regular user's followup and the scheduled reassessment and reinforcement of the pilot patients and medical personnel were taking place and the service was free of use for the duration of the validation phase (the project covered the communication cost together with the cost of the devices), it was observed a drop in usage rates although this was not the case according to the specified protocol. More specifically the usage rates as registered in the data base revealed that almost for the first month the users conformed to the specified medical protocol and their measurements were taken frequently as asked. But after that period the number of measurements started to gradually reduce. This behavior, mainly coming from the postsurgery patients, makes us conclude that the users are not willing to use frequently/daily and for long time periods ehealth monitoring devices even if they are asked to do it. According to Papadopoulos [17] this attitude can be explained by the fact that the patients do not perceive immediately the benefits of the mobile health applications since these services provide preventive medicine rather than cure.

Finally, evaluation showed that Tile-Ippokratis services are reliable, from a technical perspective. No technical problems were recorded. Users considered their interaction with the system as a positive experience which makes them consider adoption of such a system in the future. Ofcourse making this platform sustainable is a real challenge especially in low-resource settings such as the Greek context. Issues such as facilitation and maintenance of communication infrastructure, payment of license fees, communication costs, and others are considered to be the problem for sustainability of such services. Maybe local authorities could undertake the responsibility to exploit and disseminate the long-term potentiality of Tile-Ippokratis services.

5. Conclusion

The concept and realization of integrated low cost and ease of use ehealth platform for the provision of ehealth services for both patients with chronic diseases and patients who have been served by an intensive care unit have been presented in this paper. The platform based on the use of terrestrial and wireless communication infrastructures supported teleconsultation and ehealth service. The platform ensured bidirectional communication between specialized medical personnel and civilians. The platform provided equal opportunities to all citizens to have heath care services and familiarize them more with information technology.

The overall architecture of the platform has been technically tested while well-prepared scenarios have been evaluated. The evaluation results showed the feasibility of the proposed platform to be successfully used by physicians and civilians. Encouraged by these results the optimization of the platform for a wider delivery of telemedical services in the near future is under consideration. It is expected that the use of such platform will effectively improve the provision of health care services, reduce the related costs in terms of time and unnecessary transfers, and increasingly enhance the quality of life of individuals living in remote/isolated regions.

The results proved the functionality and utilization of the platform in Greece and Cyprus and the positive impact on psychological health of the participants. However, further actions are needed in order to enable the local health care systems and the different group population to be familiarized and use in their everyday live mature technological solutions for the provision of health care services.

Acknowledgments

The Tile-Ippokratis is an integrated pilot ehealth platform for improving health care provision between rural health centers in the island of Chios and the Nikosia General Hospital/intensive care unit and is founded by INTERREG III Greece-Cyprus fund. The author wishes to thank the project partners and the researchers, for their contribution and fruitful collaboration. The work they performed in these projects has provided valuable insight into some issues addressed in the present paper.

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