Intelligent Multimedia Communication for Enhanced Medical e-Collaboration in Back Pain Treatment

George Ghinea, George D. Magoulas, Andrew O. Frank*

Department of Information Systems and Computing

Brunel University, West London, U.K

email:{George.Ghinea,George.Magoulas}@brunel.ac.uk

*Department of Rehabilitation Medicine and Rheumatology

Northwick Park Hospital and Institute of Medical Research

Harrow HA1 3UJ, Middlesex

email:AndrewFrank@waitrose.com

Abstract

Remote, multimedia-based, collaboration in back pain treatment is an option which only recently has come to the attention of clinicians and IT providers. The take up of such applications will inevitably depend on their ability to produce an acceptable level of service over congested and unreliable public networks. However, although the problem of multimedia application-level performance is closely linked to both the user perspective of the experience as well as to the service provided by the underlying network, it is rarely studied from an integrated viewpoint. To alleviate this problem, we propose an intelligent mechanism that integrates user- related requirements with the more technical characterisation of Quality of Service, obtaining a priority order of low-level Quality of Service parameters, which would ensure that user-centred Quality of Perception is maintained at an optimum level. We show how our framework is capable of suggesting appropriately tailored transmission protocols, by incorporating user requirements in the remote delivery of e-health solutions.

I. INTRODUCTION

E-Health involves the electronic conveyance of medical information for the purposes of diagnosis and treatment of patients using personal computers, telecommunication links, as well as fully blown interactive multimedia involving specialized video, audio, and imaging equipment (Perednia and Allen, 1995).

In today's information intensive society, consumers of health care want to be better informed of their health options and are, therefore, demanding easy access to relevant health information. In this context, the Internet is playing a crucial role, as it serves as an inexpensive communication channel for the delivery of advanced multimedia-based health services. However, the integrated use of telecommunications and information technology in the health sector leads to new challenges in organizing, storing, transmitting and presenting health information in a timely and efficient manner for effective health-related decision-making. Innovations range from routine hospital information systems (Chan, 2000) to sophisticated AI-based clinical decision support systems (Hernando et al., 2000; Huang, Jennings, and Fox, 1995; López, et al., 2002; Roudsari et al., 2000).

The Internet has thus become an important interactive research and communication tool for both medical professionals and health consumers and one of the main drivers of the deployment of e-health applications. For example, the Internet is being tapped by many hospitals for in-house sharing of medical information and collaboration. At the clinical level, intelligent e-health applications utilizing AI, neural network, and fuzzy logic techniques are being developed to provide clinical decision-support to physicians (Hernando et al., 2000; Huang, Jennings, and Fox, 1995; López, et al., 2002; Roudsari et al., 2000).

E-health applications lead to new challenges in data transmission, as they are frequently designed to use bandwidth conservatively, at least for cross-country applications, because ubiquitous, wide area, high-bandwidth networking is not yet available (Johnson, 1999), and examination of networking requirements to support some such applications is presented in (Huston, 2000; Schnepf et al., 1995). The problem is exacerbated because the current networking foundations on which the Internet is built provide a best effort service with a minimum of service guarantees, specified in terms of Quality of Service (QoS) parameters such as delay, jitter, and loss or error rates. However, these parameters do not convey application-specific needs, such as the influence of media content and number, and the informational load on the quality of the application as perceived by e-health stakeholders. As a result, the underlying network does not consider the sensitivity of applications performance to bandwidth allocation. There is thus an architectural gap between the provision of network-level QoS and user requirements of e-health applications. This gap causes e-health systems to inefficiently use network resources and results in poor end-to-end performance which in turn has a direct negative impact on the expectations of users and clinicians.

One of the possible solutions is to construct adaptable data transport mechanisms, capable of real-time response to evolving networking, application and user requirements. To this end we present a framework which allows for not only runtime construction of tailored multimedia communication protocols, but also, through the incorporation of intelligent mechanisms, for the inclusion of user requirements in such protocols.

The structure of the paper is as follows: Section II introduces issues relating to back pain relevant to our work. The subsequent section presents a distributed collaborative e-health tool for back pain clinicians and patients that we have developed. Section IV describes the framework for the construction and operation of multiple adaptable communication protocols employed by the underlying agent-based architecture of the back pain collaborative tool. This architecture integrates technical and user requirements in the delivery of multimedia data, and is described in Section V. Lastly, an application example is provided and concluding remarks are drawn.

II. BACK PAIN

Back pain is a worldwide experience. Disabling back pain appears to be a problem for western and industrialised societies, possibly related to the development of welfare states. Thus, according to a Department of Health survey, in Britain back pain affects 40% of the adult population, 5% of which have to take time off to recover (Boucher, 1999). This causes a large strain on the health system, with some 40% of back pain sufferers consulting a GP for help and 10% seeking alternative medicine therapy (Boucher, 1999). Due to the large number of people affected, backpain alone cost industry £9090 million in 1997/8, with between 90 and 100 million days of sickness and invalidity benefit paid out per year for back pain complaints (Frank and De Souza, 2001). Back pain is not confined to the UK alone, but is a worldwide problem: in the US, for instance, 19% of all workers' compensation claims are made with regard to back pain. Although this is a lot less than the percentage of people affected by backpain in the UK, it should be noted that not all workers are covered by insurance and not all workers will make a claim for backpain (Jefferson and McGrath, 1996). Moreover, back pain does not affect solely the adult population: studies across Europe (Balague et al., 1999) show that back pain is very common in children, with around 50% experiencing back pain at some time. Any improvement in the way that patients with backpain can be analysed (and subsequently treated) should therefore be viewed as one potentially capable of significantly saving both benefit expenditure and lost man-hours.

The problem with back pain is that "there exist no standardised clinical tests or investigations by which all people with low back pain can be evaluated" (Papageorgiou et al., 1995). Nor will there ever be, as different people have different pain thresholds and will be affected differently. It is also difficult for medical personnel to know what has caused the backpain, as there are potentially many different causes behind it (Frank and De Souza, 2001). Not only is evaluation difficult, but, unfortunately, like most types of pain, back pain is also difficult to analyse, as the only information that can be used is suggestive descriptions from the patient. The need therefore for distributed, collaborative applications which allow communication and exchange of information between consultants, physiotherapists, and patients, becomes paramount.

The main medical work that is undertaken to resolve backpain tends to be with patients that have chronic backpain. However, these patients may have developed psychological and emotional problems, due to having to deal with the pain. Because of these problems, patients can have difficulty describing their pain, which can lead to problems during the treatment. In some patients, the psychological problems may have aided the cause of the backpain, by adding stress to the body, or the stress of the backpain may have caused psychological problems (Ginzburg et al., 1988; Parker et al., 1995). It is because of this factor that patients suffering from backpain are usually asked to fill out questionnaires of different types in order to help the medical staff, not only to know where the pain is located, but also to identify the patient's mental state before treatment begins. In addition, the patient is usually required to mark on a diagram, usually of a human body, where the pain is located, and the type of pain. This type of diagram is known as a 'pain drawing' and is exemplified in Figure 1. Pain drawings have been successfully used in pain centres for over 50 years (Palmer, 1949) and act as a simple self-assessment technique, originally designed to enable the recording of the spatial location and type of pain that a patient is suffering from (Parker et al., 1995) They have a number of advantages including being economic and simple to complete, and can also be used to monitor the change in a patient's pain situation (Ohnmeiss et al., 1995).

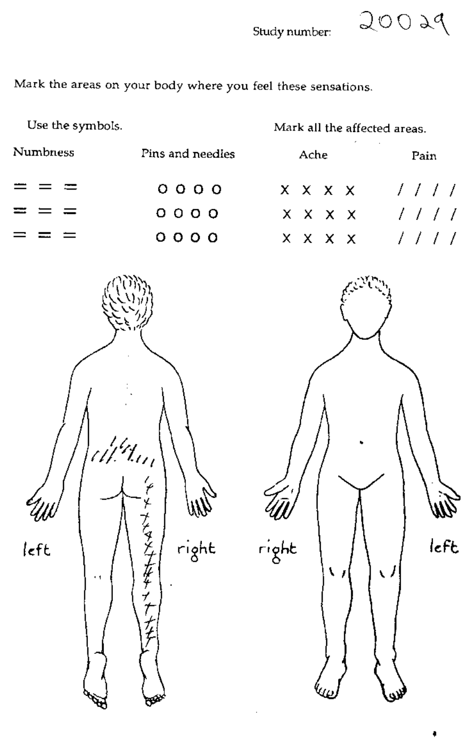

Figure 1 Pain drawing.

In a back pain scenario, traditional approaches on the part of doctors concentrate on the exclusion of pathology, when what patients need is understanding of their problems, alleviation of their symptoms and encouragement that activity is not harmful, but therapeutic. It is in precisely this context that e-health applications need to be developed which bring the information required to the patient and facilitate communication with the clinical consultant. Such activities are mediated by communication technologies and provide information which the patient can access in his/her home or at the local clinic, if domestic connectivity is an issue. These remarks are especially applicable in Britain, where the relative scarcity of back-pain rheumatology consultants, on the one hand, coupled with the widespread occurrence of back-pain in the general public, necessitates that technology, especially multimedia communication-related, be exploited in new ways. Whilst the idea of distributed collaborative environments for long-distance consultations and diagnostic is, by itself, not new, what is novel in our approach is the exploitation of multimedia perceptual results to optimise resource usage in data transmission.

III. A COLLABORATIVE E-HEALTH TOOL FOR BACK PAIN CONSULTATION

We have developed a distributed collaborative tool for back pain clinicians, a snapshot of which is given in Figure 2. Features of the system include videoconferencing, database connectivity to index/retrieve information relating to the relevant content of the videos of patients describing their pain, instant messaging/chat, an integrated pain drawing, as well as video transmission and playback. Thus, users can communicate with one another via a web cam, needing only to specify the I.P. address of the person they wish to transmit to and the port number they wish to stream images from their web camera through in order to set-up a videoconferencing session.

A separate panel of the application enables users to ‘instant message’ each other in a familiar, chat-room environment. In addition, if microphones are installed, users can pursue a conversation using the application. Whilst the video and audio connections as well as the messaging facility allow the exchange of information (such as visual, verbal and textual descriptors of pain being experienced) between users of the system, the use of a shared back pain drawing, in which the body surface is regionalized into dermatomes (Figure 3), would enable both clinicians and patients to accurately point the location of the pain. Moreover, the clinician has access to a database of back pain data, which can be connected to by clicking on the relevant dermatome corresponding to the precise location of the pain, as indicated by the patient on the pain drawing.

Figure 2 Snapshot of e-collaboration system for back pain treatment

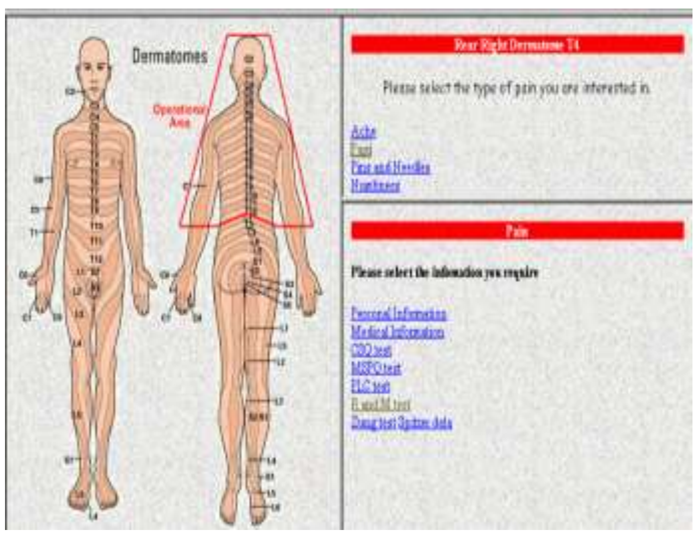

Figure 3 Dermatome-based back pain locator

Lastly, the implemented collaborative application also allows users to transmit pre-recorded videos (such as medical training videos or physiotherapy clips) to other patients, GPs and stakeholders using the system. Notwithstanding this functionality, the developed e-health application is also novel in that it employs a framework for intelligent and dynamic protocol management to achieve the transparent and adaptive transmission of its multimedia data, depending on network conditions and a set of predefined user requirements, as shall be described in the next sections.

IV. A FRAMEWORK FOR PROTOCOL ADAPTATION

Multimedia delivery in e-health systems is characterized by a wide spectrum of dynamically varying QoS requirements, which must be negotiated, re-negotiated and managed in response to changing network and end-system conditions, or to new expectations from the human user. Thus in an e-health context, it is precisely this (re)negotiation and dynamic management of applications' QoS that emphasises the need for adaptable protocols - protocols that are capable of modifying their execution pattern to suit their changing environment. It is therefore clear that any new solution, which attempts to efficiently deal with the problem of e-health QoS provisioning, must of necessity be adaptive. Moreover, with adaptive protocols, applications need not know their resource requirements in advance in order to be provided with a predictable QoS.

Reconfigurable protocols represent a particular subset of adaptive protocols in which adaptation is provided for through the dynamic linking of protocol functions at connection establishment time (Sookavatana et al., 2001). Such protocols attempt to overcome inefficiencies linked with generic adaptive protocols catering for a wide range of applications by configuring a per-application tailor made functionality. Thus, dynamic configuration can be employed to adjust the protocols used so that 'heavyweight' protocol functions can be used only when required, and in previous work we have explored, with encouraging results, the feasibility of this approach (Ghinea et al., 1999).

The *Dynamically Reconfigurable Stacks Project* (DRoPS) provides an infrastructure for the implementation and operation of multiple adaptable protocols (Ghinea et al., 1999). DRoPS-based communication protocols are composed of fundamental mechanisms, called *microprotocols*, which perform arbitrary protocol processing operations. The complexity of processing performed by a microprotocol is not defined by DRoPS and may range from a simple protocol function, such as a checksum, to a complex layer of a protocol stack, such as TCP. In addition, protocol mechanisms encapsulated within a microprotocol may be implemented in hardware or software. If appropriate hardware is available, the microprotocol merely acts as a wrapper, calling the relevant hardware function. Microprotocols are encapsulated in loadable modules, allowing code to be dynamically loaded into a running operating system and executed without the need to recompile a new kernel. Each such microprotocol can be implemented via a number of adaptable functions, as detailed in Table 1. In particular, microprotocols may also represent the absence of a particular function, such as the one representing no sequence control in Table 1.

Protocol mechanism	Implementations
Sequence control	none | complete
Flow control	none | window based
Acknowledgement scheme	IRQ | PM-ARQ
Checksums	none|block check|full CRC

Table 1 Adaptable functionality in DRoPS

Whilst a protocol defines the structure and resources available for constructing a communication system, a *protocol stack* defines a unique instantiation assigned to a particular connection. In terms of microprotocols, a protocol stack is an ordered set combined to form a functional communication system. Each connection is assigned a protocol stack for its sole use, the configuration of which may vary according to the characteristics of the particular connection. Using this model, individual flows within individual sessions may be uniquely configured to provide an appropriate service. Thus, a connection between a video client and server may use a semantically strong protocol for interactivity commands (play/forward/rewind) and a relatively weak one for bulk transfer of relatively loss tolerant video data, such as a clip illustrating common back problems.

The DRoPS core architecture is embedded within the Linux operating system, is accessible through standard interfaces, such as *sockets* and the UNIX *ioctl* (I/O control) system calls, has direct access to network devices and benefits from a protected, multiprogramming environment. The architecture allows additional QoS maintenance techniques, such as flow shaping, at the user or interface level, and transmission queue scheduling, at the device queue level.

The DRoPS framework does not place restrictions on the implementation of particular protocol functionalities. For instance, an acknowledgement protocol can be implemented either as an Idle Repeat Request (IRQ) or a Per Message Acknowledgement Scheme (PM-ARQ). However, the decision behind implementation choices of particular protocols is not straight-forward, for it has to deal with inherent imprecision either at the network or user levels. An intelligent mechanism is needed to handle such situations, and is described in the next section.

V. AGENT-BASED MECHANISMS FOR INTELLIGENT PROTOCOL MANAGEMENT

We have integrated the DRoPS framework for construction of adaptable, tailor-made protocols into an agent-based architecture which combines QoS and user considerations and is able to intelligently manage the latter bearing in mind the dynamically fluctuating QoS. The diagram of this architecture is given in Figure 4 and shows how a *QoS monitoring agent* and *a user agent*, consulting a *perceptech* database of joint perceptual and technical information, communicate updated QoS information as well as user choices and preferences, respectively, to the *integration agent*. Based on this information, the integration agent then decides on a suitably tailored protocol stack to use in the respective situation. This protocol stack configuration is then transmitted to the *DRoPS adaptation agent* which then appropriately reconfigures the protocol stack, thus ensuring that the overall goal of the architecture, namely that user requirements are maintained at an optimum level given the prevailing network conditions, is achieved in practice. This situation is in contrast to traditional legacy protocol stacks such as TCP/IP and UDP, which make no allowance for user-related considerations in their functionality. Now that an overview of the agent-based architecture has been given, we proceed to describe its constituent components.

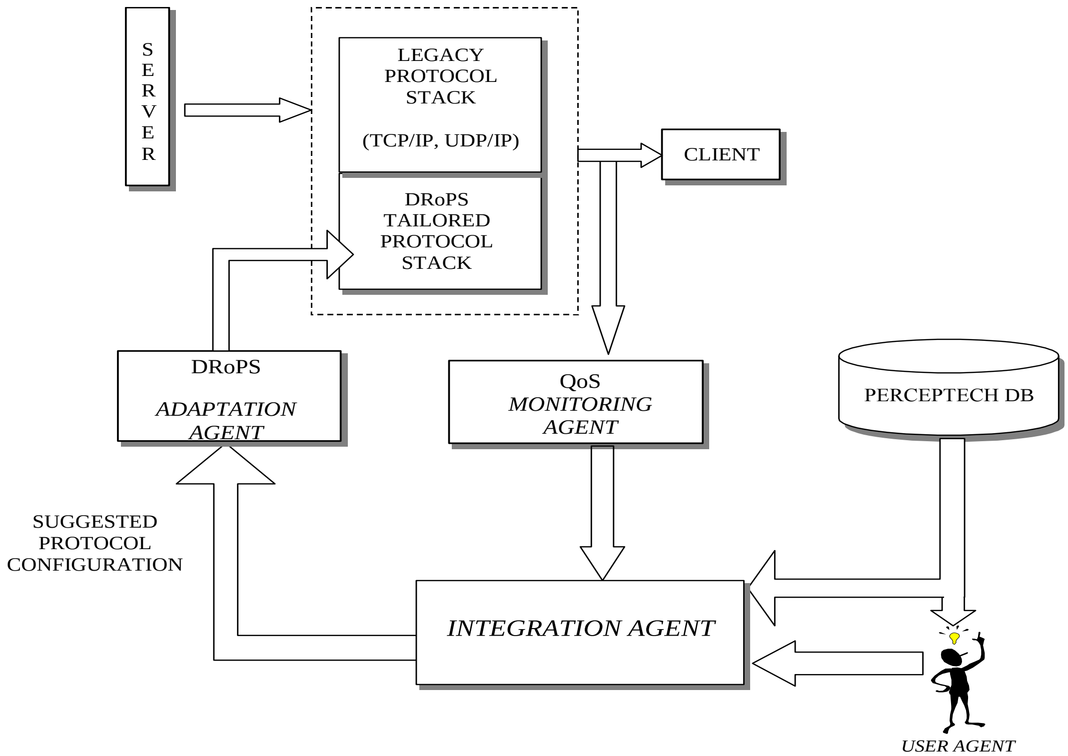

Figure 4 Integrated architecture for protocol management

V.A. The QoS Monitoring Agent

Consistent with the DRoPS framework, 5 network level QoS parameters have been considered in our model: Bit Error (*BER*), Segment Loss (*SL*), Segment Order (*SO*), Delay (*DEL*) and Jitter (*JIT*). The QoS monitoring agent is in charge of periodically collecting network information, through appropriate monitoring of the 5 QoS parameters used in our architecture. We use threshold-based classification schemes to categorise the monitored values, based on results from the literature regarding huma perceptual tolerance levels to QoS distortions (Blakowski and Steinmetz, 1996; Kawalek, 1995) (Table 2). To speed up the process we have mapped the values of low, medium and high, for each of the QoS parameters considered to the intervals (0;3], (3,6], and (6,9], respectively.

QoS parameter	Threshold Values		
	Low	Medium	High
Delay	<80ms	80 –120ms	>120ms
Jitter	<1 LDUs	1-2 LDUs	>2 LDUs
Segment Loss	<2% (audio) <19% (video)	2-20% (audio) 19-64% (video)	>20% (audio) > 64%(video)
Bit Error Rate	<5%	5-25%	>25%
Segment Order	<7%	7-28%	>28%

Table 2 QoS threshold values (LDU = Logical Data Unit)

The rationale for determining the relative importance has its origins in psychology. Psychological experiments have shown that individuals cannot simultaneously compare more than 7 objects (±2) (Miller, 1956). Thus, pairwise comparisons are usually quantified by using a scale of nine grades. The 9-grades scale has been compared with several other scales and seems to come the closest to representing individual judgement about reality when compared with actual measures of reality already identified (Saaty, 1974). Following this idea, the QoS monitoring agent employs a 9-grades scale using the following conventions: 1 → *"equally important"* (EI); 2 → *"slightly more important"* (SMI); 1/2→ *"slightly less important"* (SLI); 3 → *"weakly more important"* (WMI); 1/3 → *"weakly less important"* (WLI); 4 → *"moderately more important"* (MMI); 1/4 → *"moderately less important"* (MLI); 5 → *"essentially important"* (EI); 1/5 → *"essentially less important"* (ELI); 7 → *"demonstrably important"* (DI); 1/7 → *"demonstrably less important"* (DLI); 8 → *"highly important"* (HI); 1/8 → *"highly less important"* (HLI); 9 → *"absolutely important"* (AI); 1/9 → *"absolutely less important"* (ALI). Thus, the agent then determines the relative importance of each QoS pararemeter with respect to one another through pairwise comparisons: the ratio of the two parameters is taken and, if this ratio is supra-unitary, the ceiling function is applied, otherwise the ceiling function is applied to the reciprocal of the value, and then inversed once more.

The decision of the QoS monitoring agent is stored in a 5×5 matrix as detailed in Table 3 and communicated to the integration agent. Thus, for a particular networking environment Table 3 illustrates that Delay is “demonstrably important” compared to Bit Error Rate, while Segment Loss and Segment Order are “equally important”.

	BER	SO	SL	DEL	JIT
BER	**EQI**	SLI	SLI	DLI	ELI
SO	SMI	**EQI**	EQI	ELI	SLI
SL	SMI	EQI	**EQI**	ELI	SLI
DEL	DI	EI	EI	**EQI**	SMI
JIT	EI	SMI	SMI	SLI	**EQI**

Table 3 Example of a decision matrix built by QoS monitoring agent

V.B. The User Agent

The concept of quality in distributed multimedia systems is indelibly associated with the provision of an acceptable level of application performance. Ultimately this performance is itself dependent on:

- the user’s experience with the multimedia presentation which we define as Quality of Perception (QoP). QoP has two main components: a user’s ability to analyse, synthesise and assimilate the informational content of multimedia applications, as well as his/her subjective satisfaction with the quality of such applications.
- the QoS provided by the underlying network.

Whilst the focus in the telecommunications community has rested on the latter, it is our belief that it is indeed the former measure of quality which needs to be concentrated on in order for e-health applications to proliferate and gain increased acceptance in the medical community. Previous work on QoP (Ghinea and Thomas, 1998; Ghinea and Magoulas, 2001), based on extensive user tests, has shown that technical-oriented QoS must also be specified in terms of perception, understanding and absorption of content - Quality of Perception in short - if multimedia presentations are to be truly effective. Thus, for example, users have difficulty in absorbing audio, visual and textual information concurrently. In a multimedia based e-health environment (such as a remote video-based diagnostic system), if the user perceives problems with the presentation (such as synchronisation problems between different component media), users will disregard them and focus on the contextually important medium. This implies that critical and important messages in a multimedia presentation should be delivered in only one type of medium, or, if delivered concurrently, should be done so with maximal possible quality.

Three QoP parameters are considered in our framework. These are the relative importance of the Video (V), Audio (A) and Textual (T) components as conveyors of information in the context of the presentation. The user agent is in charge of computing the relative importance of these parameters with respect to one another – these might change depending on the applications being transmitted and on user preferences, which are stored in the perceptech database. Whilst our architecture does not preclude the storage of individual user profiles in this database, the default information contained in this database is based on comprehensive user QoP tests (Ghinea and Thomas, 1998), and thus absolves users of our e-health application from the need to specify their particular preferences if they do not want to.

To this end, the user agent constructs, based on the subject matter being utilised by the e-health application and the relevant QoP information contained in the perceptech database, a 3×3 decision matrix and communicates it to the integration agent. Thus, for instance if only the chat room functionality of the e-health application is being used, then text becomes “demonstrably important” compared to all other parameters; on the other hand, if an online consultation with a patient is being undertaken, then, whilst occasional video frames might be dropped without too much of a negative perceptual effect, it is paramount that the audio descriptors are being received with as little loss as possible. Thus, in this case, audio would become “essentially important” compared to video and “absolutely important” compared to text as detailed in Table 4, since the video shots are not expected to contain dynamic sequence changes and no use is being made of text-chat facilities.

	V	A	T
V	**EQI**	ELI	MMI
A	EI	**EQI**	AI
T	MLI	ALI	**EQI**

Table 4 Example of decision matrix built by the user agent

V.C. The Perceptech Database

As has been mentioned, the perceptech database contains combined perceptual-technical information, linking the 5 QoS parameters with the 3 QoP parameters considered in our model. It thus encapsulates knowledge on how the DRoPS microprotocols impact on each of the QoS and QoP parameters, as well as knowledge detailing the balance between the relative importance of QoS and QoP parameters for a given application, user, and network scenario. An example of the former type of knowledge contained in the perceptech database is given by the matrix of Table 5: here the microprotocols are compared with respect to audio (A), a QoS parameter. The notation adopted henceforth is as follows: no sequence control (micro1), strong sequence control (micro2), no flow control (micro3), window-based flow control (micro4), IRQ (micro5), PM-ARQ (micro6), no checksum algorithm (micro7), block checking (micro8), full Cyclic Redundancy Check (micro9).

Audio	micro1	micro2	micro3	micro4	micro5	micro6	micro7	micro8	micro9
micro1	**EQI**	EI	EQI	EI	WMI	EI	EQI	WMI	EI
micro2	ELI	**EQI**	MLI	EQI	EQI	EQI	DLI	EI	WMI
micro3	EQI	MMI	**EQI**	EI	WMI	EI	EQI	WMI	EI
micro4	ELI	EQI	ELI	**EQI**	WMI	ELI	DLI	ELI	WLI
micro5	WLI	EQI	WLI	WLI	**EQI**	WMI	WLI	EQI	WMI
micro6	ELI	EQI	ELI	EI	WLI	**EQI**	ELI	WMI	EQI
micro7	EQI	DI	EQI	DI	WMI	EI	**EQI**	MMI	EI
micro8	WLI	ELI	WLI	EI	EQI	WLI	MLI	**EQI**	EI
micro9	ELI	WLI	ELI	WMI	WLI	EQI	ELI	ELI	**EQI**

Table 5 Matrix describing microprotocol impact with respect to audio

As it can be observed from Table 5, micro1, micro3 and micro7 are of the same importance and are also the most important protocols with respect to the audio criterion. This should come as no surprise if one takes into account that, due to the real-time nature of many distributed multimedia applications and the perceptual tolerance of humans to occasional corruption of data, it is sometimes more important for a transport protocol *not* to have any functionality which might add to the processing/presentation time of the media unit. This observation explains the prime importance of micro1, micro3 and micro7 (which represent the *absence* of sequence, flow, and error controls, respectively).

The perceptech database also incorporates knowledge emphasising the relative importance of QoS and QoP parameters for user-, network-, or application-specific scenarios. For example, in the not infrequent case of high network delays being experienced, such knowledge is given by the matrix of Table 6. Moreover, such stored information is usually generic (highlighting the importance of specific QoP parameters with respect to all others in the case of disabled users, such as those that are hard-of-hearing or visually-impaired), but can also be user-specific.

	V	A	T
BER	EQI	EQI	EQI
SO	EQI	EQI	EQI
SL	EQI	EQI	EQI
DEL	**DI**	**DI**	**DI**
JIT	EQI	EQI	EQI

Table 6 Matrix describing knowledge emphasising the relative importance of QoP and QoS parameters in the case of high network delays

V.D. The Integration Agent

The knowledge of the environment, internal states and the impact of other agents that the integration agent acquires can be thought of as being assembled from a number of components, communicated by the other agents and the perceptech database (see Figure 5). The integration agent exhibits a goal-directed behaviour using a reasoning mechanism which is based on Multicriteria Decision Making (MDM) as the decision making process must marry a range of technical factors against a set of decision criteria (user preferences, constraints). An approach to dealing with this problem is to prioritise criteria and then measure the performance of factors that contribute to each criterion.

To be more precise, agent's goal of intelligently construct communication protocols that satisfy constraints set by the networking environment and the user is achieved by adopting the Analytic Hierarchy Process (AHP) formalism, which is one of the most popular methods of Multicriteria Decision Making (MDM) (Ching-Lai and Kwangsun, 1981). The AHP formalism, originally proposed in (Saaty, 1977), has been successfully applied in solving real world multi attribute decision making problems in different areas, such as in Management Science and Computer Science (Akash et al., 1999; Chan et al., 2000a; Chan et al., 2000b; Karsak and Tolga, 2001). The capability to handle subjective criteria and inconsistencies in the reasoning process and the conceptual simplicity of that method are the major reasons of its popularity. Indeed, this characteristic is very important in our context as the dynamic nature of our problem results in situations where the technical information and the perceptual information introduce inconsistencies in the knowledge structures of the integration agent.

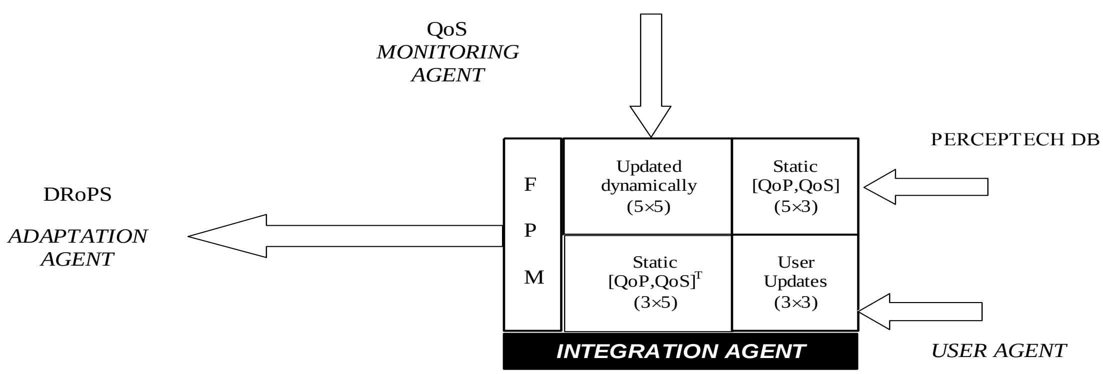

Figure 5 Integration of QoP and QoS knowledge based on agent communication

Following the AHP formalism the integration agent constructs a hierarchy of factors that may be have changing degrees of importance as the agent continues its operations to integrate information from other agents. The hierarchy consists of three major components, as illustrated in Figure 6. The first level of the hierarchy is used to denote the overall objectives or goals of the problem, i.e. find a microprotocols' configuration that satisfies all constraints. The second level is occupied by criteria for assessing the accomplishment of the goal (satisfy technical and user considerations/preferences), while the third level contains available actions or alternatives (microprotocols).

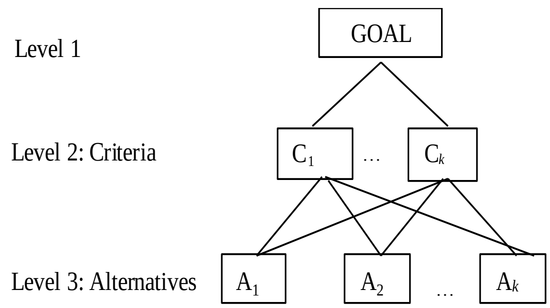

Figure 6 Decision hierarchy of the integration agent.

In its existing form, the integration agent considers eight criteria (5 technical and 3 user-related considerations) and nine microprotocols. As shown in Figure 5, the knowledge structure constructed by the integration agent can be conceptually split up into three components: one dealing exclusively with user issues, one solely with QoS judgements, whilst the last reflects the balance between user and QoS considerations. As already mentioned, within our framework, each multimedia application can be characterised by the relative importance of the video (V), audio (A), and textual components (T). At this point, it should be mentioned that the user agent part of the structure is the only part evaluated by the end-user according to his preference regarding his/her priorities attached to the three components considered in the user agent. In the QoS agent, five network level QoS parameters are considered: BER, SL, SO, DEL and JIT.

The reasoning system of the integration agent results in a decision, i.e. a suggested protocol configuration that is communicated to the DRoPS adaptation agent. Reasoning consists of two stages:

1. *Comparisons pairing* to yield preference weights priorities. The main task of this stage is to determine numerical measures to the relative importance of the criteria and to the relative performance of the alternatives on these criteria. It consists of two sub-procedures:

   1.1 Determine the relative importance of the criteria

   1.2 Determine the relative standing of each alternative with respect to each criterion.

2. *Synthesis of preference weights* to yield composite priorities for alternatives.

In Step 1.1 the priority weights w_i, i=1,…p denoting the relative importance of each criterion i among the p criteria (a higher priority setting corresponds to a greater importance) can be evaluated using different weight determination procedures, such as the Eigenvector method (Saaty, 1977), the Logarithmic Least Square method (Crawford and Williams, 1985; Saaty, 1990), the Goal Programming method (Bryson, 1995) or the Fuzzy Programming method (Mikhailov and Singh, 1999a; Mikhailov, 2000).

In Step 1.2, pairs among alternatives are also compared with respect to the ith criterion and then a weight $w_{j,i}$, which denotes how preferable is the alternative j with respect to the criterion i, is derived. There is a total of $p(p-1)/2$ pairwise comparisons in the matrix and weights can be calculated using any one of the methods (Bryson, 1995; Crawford and Williams, 1985; Mikhailov and Singh, 1999a; Mikhailov, 2000; Saaty, 1977). At this point it is important to note that the quality of the weighted priorities is highly affected by the consistency of the judgements of the decision maker. When the decisions of the user and QoS agents are perfectly consistent, then all the elements a_{ij} have perfect values and the consistent priorities are unique. However, in our case the evaluations a_{ij} are frequently not perfect, as they are just estimations based on the best available data. Furthermore, as a result of the dynamic nature of our problem, there are cases when the technical information and the perceptual information introduce inconsistencies in the knowledge structure. Thus, a weight determination technique suitable to handle inconsistencies is indispensable, as will be explained below.

Finally, in Step 2, the weighted sum model, (Triantaphyllou. and Lin, 1996), is used to find the preference of an alternative *j* with respect to all criteria simultaneously; preference is defined by P_j and denotes the overall priority, or weight, of action *j*:

$$P_j = \sum_{i=1}^{p} w_i \cdot w_{j,i} \,. \tag{1}$$

Obviously, in the maximisation case, the best alternative is the one that possesses the highest priority value among all others.

As already mentioned, the dynamic nature of our problem requires the use of a weight determination technique able to handle inconsistencies. Therefore, the Fuzzy Programming Method (FPM), which is a method capable to solve even high inconsistent matrices, was used (Mikhailov and Singh, 1999b; Mikhailov, 2000). FPM is based on a geometrical representation of the prioritisation process as an intersection of hyperlines and determines the values of the priorities, corresponding to the common intersection point of all hyperlines. In case of inconsistent matrices, the hyperlines have no common intersection point. i.e. the intersection set is empty. Thus, FPM represents the hyperlines as fuzzy lines and finds the solution of the approximate priority assessment problem, as an intersection point of these fuzzy lines, i.e. it finds a fuzzy intersection region that contains many points with different degrees of membership in this region, and determines the values of the priorities, corresponding to the point with the highest measure of intersection. In (Mikhailov and Singh, 1999b), it is shown that FPM is able to produce better results than other methods when the degree of inconsistency is high.

The usage of the FPM enables integration and processing of knowledge that is expressed either as crisp, interval or fuzzy number matrices. Each reciprocal pairwise comparison matrix, $A=[a_{ij}]\in\Re^{p\times p}$, can be represented as a system of $m = p(p-1)/2$ linear equalities:

$$\mathrm{R}w = 0, \tag{2}$$

where n is the number of elements compared, w is the vector of priority weights and $\mathrm{R}\in\Re^{m\times p}$. For the inconsistent cases, the FPM finds a solution that approximately satisfies Equation (2), i.e. $\mathrm{R}w \approx 0$.

One of the most important advantages of the FPM is that the prioritisation problem is reduced to a fuzzy decision making problem that can be easily formulated and solved as a standard linear programming problem (Mikhailov, 2000):

Goal: $max\ \lambda$

$$\begin{gathered}\text{Subject to } \lambda d_k + \mathrm{R}_k w \le d_k,\ \ k = 1,\ldots, m,\ \ 1 \ge \lambda \ge 0 \\ \sum_{i=1}^{p} w_i = 1,\ w_i > 0,\ i = 1,\ldots, n,\end{gathered} \tag{3}$$

where the values of the tolerance parameters d_k represent the admissible interval of approximate satisfaction of the crisp inequalities $\mathrm{R}_k w < 0$. For the practical implementation of the FPM, it is reasonable all these parameters, d_k, to be set equal (Mikhailov and Singh, 1999a; Mikhailov, 2000). The optimal solution to the problem (3) is a vector (w^*, λ^*), which first component maximises the degree of membership of the fuzzy feasible area set, and the second one gives the value of the maximum degree of satisfaction.

After deriving the underlying weights from the comparison matrices through the FPM technique, the priority weights, w_i, and the relative scores, $w_{j,i}$, are synthesised following the Weight-Sum Model. The overall priority value P_j of the j^{th} alternative, A_j (j=1,…k), is expressed as in Relation (1). Obviously, the alternative with the maximum overall value P_j will be chosen.

V.E. The DRoPS Adaptation Agent

The *DRoPS adaptation agent* is in charge of synthesising a new, tailored, protocol stack, based on the suggestion of the integration agent. A protocol defines header formats, private data structures and an unordered set of microprotocols from which communication systems may be fabricated. Individual protocols are differentiated by these characteristics as well as the semantics of the protocol. In terms of microprotocols, a DRoPS protocol stack is an ordered set drawn from some *parent* protocol and combined to form a functional communication system. Each connection is assigned a protocol stack for its sole use, the configuration of which may vary from other stacks derived from the same parent.

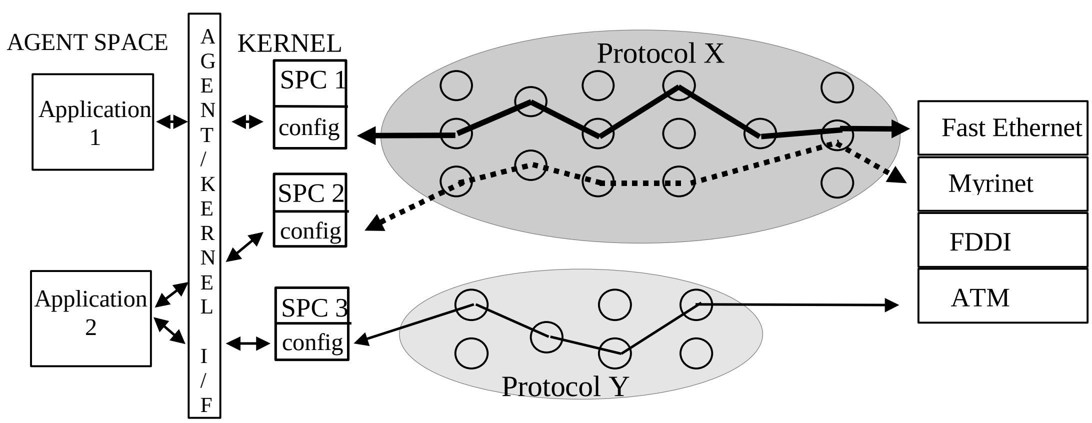

Figure 7 Dynamic synthesis and reconfiguration of protocols in DRoPS

Whilst the current definition of a protocol stack specifies its components and structure, it does not define any relation to applications, other DRoPS entities or the operating system as a whole. Figure 7 provides an overview of the major system components that form the DRoPS architecture and defines their interaction. Microprotocols are represented as small circular objects and are divided between two protocols X and Y. A Sub Protocol Controller (*SPC*) is associated with each connection. Its primary function is to represent attributes unique to an individual connection, such as protocol configuration, connection characteristics, user QoP requirements and private protocol data. Figure 7 depicts a protocol stack as an undulating line connecting an SPC to a particular network device. The microprotocols intersected by this line form the stacks configuration and are defined by the associated SPC.

Three operations, *exclude, include* and *exchange*, are used by the DRoPS agent to manipulate the configuration of a protocol stack. The exchange operation manipulates the stack configuration, stored within the associated SPC, routing data from subsequent messages through a different set of microprotocols. In addition, each SPC contains an *activation field* defining the active microprotocols in the current configuration. The inclusion or exclusion of a microprotocol from a stack is achieved by the manipulation of this mask in one of two modes; temporary and permanent. The former excludes a microprotocol, or set of microprotocols, for one message only, whilst the latter maintains the modification until otherwise notified. End points are notified of reconfiguration either by explicit control messages sent either over a dedicated channel or piggybacked on protocol data. The overhead of an include/exclude operation has been measured at 0.2μs and the exchange operation at a slightly more expensive cost of 2.8μs (Ghinea et. al., 1999). These times are incurred only once at each endpoint, for each adaptation, and are justified by the overall improvement in performance that adaptation yields.

Once a suggested protocol configuration is received from the integration agent, it is then sanity checked to ensure validity. The result of this processing is a set of *include*, *exclude* and *exchange* commands that cause DRoPS to perform reconfiguration at the relevant end points of communication.

VI. APPLICATION SCENARIO

As an example of our work, we treat the cases whereby one QoS parameter is *"demonstrably important"* with respect to all the other parameters considered in our model. This situation is not farfetched and can easily arise in real-life situations, particularly when component parts of networks fail or malfunction. Thus, for instance, if a link between two routers goes down, then connections using that link will experience a high degree of segment loss; alternatively, if there is a fault in router hardware, then connections involving that router might, for instance, experience high bit error rates. It must be mentioned, though, that failure or malfunction of network components is not the only possible scenario here: a less dramatic situation, where there is no such failure or malfunction, but where connections experience high levels of delay (due to network congestion) are the norm rather than the exception in networks such as the Internet.

In this section, we present experiments illustrating the ability of our approach to select appropriate micro-protocols and construct a suitably-tailored protocol stack depending on the prevailing operating network environment.

Priorities	micro1	micro2	micro3	micro4	micro5	micro6	micro7	micro8	micro9
Initial	0.0982	**0.1684**	0.0922	0.1361	0.0847	0.1279	0.0868	0.0674	0.1373
Updated	**0.1262**	0.1259	0.1154	0.1186	0.0819	0.1095	**0.1337**	0.0739	0.1251

Table 7 Overall weights of the alternative microprotocols for the experiment

In Table 7 our methodology has been applied to a situation where DRoPs is experiencing protracted delays due to network congestion. As a result of a delay-intolerant audio transmission being subjected to a period of high network delays, the QoS monitoring agent will communicate this situation to the integration agent. In Table 7 we can see that the priorities of the different microprotocols obtained through our approach change from the initial configuration, biased towards micro2 (an overall value of 0.1684 was assigned to that microprotocol initially), to an updated one in which micro7 and micro1 are top of the priority ordering. This means that the priority ordering of the microprotocols would change to one which favours microprotocols that do not lead to extra delays, as one would expect. In our case, these are represented by micro1 and micro7.

In Figure 8 we show the resulting protocol stack which is constructed using our approach in the DRoPS framework, when each of the QoP and QoS parameters becomes, in turn, of primary importance. Such a scenario is not inconceivable, particularly when component parts of networks fail or malfunction. Thus, for instance, if a link between two routers goes down, then connections using that link will experience a high degree of segment loss; alternatively, if there is a fault in router hardware, then connections involving that router might, for instance, experience high bit error rates. Thus, in the case where segment loss (SL) is of primary importance then, as can be seen from Figure 8, the DRoPS protocol stack is made up of micro1, micro4, micro6 and micro7. Whilst the choice of micro6 is to be expected, as it is the only microprotocol in the DRoPS framework explicitly able to handle losses, the choice of micro4 highlights the importance of flow control for segment losses, which would prevent, for instance, buffer overflows and the resulting loss of data. Otherwise, the choice of micro1 and micro7 reflect the streamlined functionality of the protocol stack, as these microprotocols, by not acting on sequence control and bit errors, respectively, reduce computational overhead.

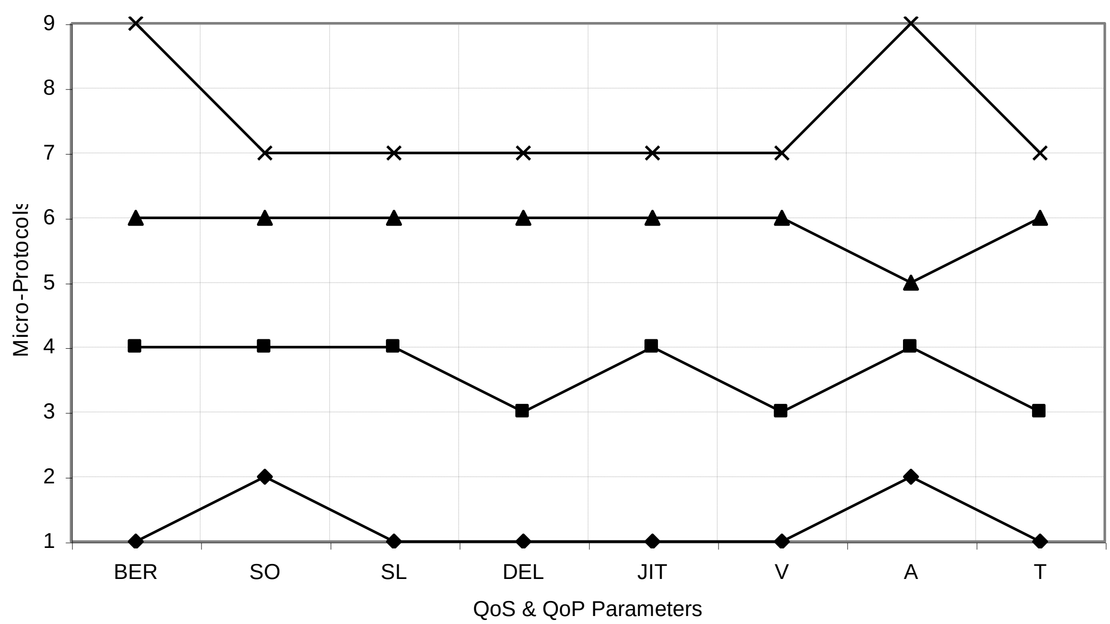

Figure 8 Resulting DRoPs protocol stack when QoS and QoP parameters are, in turn, of primary importance.

Similar observations apply in the case when QoP parameters are of primary importance. Accordingly, all media components of multimedia presentations are tolerant to bit errors, except audio. Thus, the case when audio is considered of primary importance is the only one in which the resulting protocol stack includes in its configuration micro9, the most suited microprotocol to handle bit errors. The fact that most distributed multimedia applications have real-time constraints as well as being tolerant to bit errors, is reflected in the choice of the "no-frills" micro7 in all other cases, for this type of functionality. The delay-intolerant nature of our collaborative e-health tool is also reflected in the choices of micro1 and micro3 in the suggested protocol stacks when video and text are of primary importance. The choice of micro6 for these two scenarios reflects, however, the importance of not losing segments of information, particularly in the case of compressed media, as any loss of information would propagate through subsequent media units, bearing in mind the widespread exploitation of differential characteristics in compression.

VII. CONCLUSIONS

The deployment of Internet-based applications for patient care using advanced multimedia techniques aims to offer users of health services high-quality care over inexpensive communication pathways, using Internet-based, interactive communication tools. However, the integrated use of telecommunications and information technology in the health sector leads to new challenges in data transmission, due to the fact that distributed multimedia e-health applications have a set of task-specific requirements which must be taken into account if effective use is to be made of the limited resources provided by public telecommunication networks.

In this paper, we have presented an agent-based architecture for a distributed collaborative e-health multimedia application which incorporates an intelligent mechanism of obtaining a priority order of low-level QoS parameters, which would ensure that expected user quality is maintained at an acceptable level across dynamically varying network conditions. Our approach factors multimedia-enhanced e-health applications along several axes and bridges the application-network gap by integrating Quality of Perception-related requirements with the more technical characterisation of Quality of Service. We have applied our framework to suggest appropriately tailored transmission protocols by incorporating human-perceptual requirements in the remote delivery of e-health solutions.

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