Intelligent Protocol Adaptation for Enhanced Medical e-Collaboration

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Abstract

Distributed multimedia e-health applications have a set of specific requirements which must be taken into account if effective use is to be made of the limited resources provided by public telecommunication networks. Moreover, there is an architectural gap between the provision of network-level Quality of Service (QoS) and user requirements of e-health applications. In this paper, we address the problem of bridging this gap from a multi-attribute decision-making perspective in the context of a remote collaborative environment for back pain treatment. We propose an intelligent mechanism that integrates user- related requirements with the more technical characterisation of Quality of Service. 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.

Introduction

Telemedicine can be broadly defined as the use of telecommunications technologies to provide medical information and services. E-Health is a particular branch of telemedicine involving 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).

Although the business world has long adopted practices such as teleconferencing and telecommuting, telemedicine, whilst not a stranger to these emerging technologies, comes with its own additional set of challenges because of the highly complex world of medicine. Simultaneously, 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. The challenge therefore lies in using various forms of information technology to organize, store, and present health information in a timely and efficient manner for effective health-related decision-making. Innovations range from routine hospital information systems (Chang 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 deployment of e-health applications for patient care using advanced multimedia techniques aim 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. An examination of networking requirements to support some of these applications is presented in (Huston 2000; Schnepf et al. 1995). Telemedicine applications 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).

The problem is exacerbated because 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 multicriteria decision making, for the inclusion of user requirements in such protocols.

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, Seneviratne and Landfeldt, 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, Thomas, and Fish 1999).

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

The *Dynamically Reconfigurable Stacks Project* (DRoPS) provides an infrastructure for the implementation and operation of multiple adaptable protocols (Ghinea, Thomas, and Fish 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, micro-protocols may also represent the absence of a particular function, such as the one representing no sequence control, as shown in Table 1.

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 video client and server applications may use a semantically strong protocol for commands and a relatively weak one for bulk transfer of relatively loss tolerant graphical data.

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. A mechanism is needed to handle such situations, and is described in the next section.

A Mechanism for Protocol Adaptation

Our approach factors multimedia-enhanced e-health applications along several axes. These are the relative importance of the Video (*V*), Audio (*A*) and Textual (*T*) components as conveyors of information, as well as the Dynamism (*D*) of the presentation. On the other hand, 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*). Our aim is to construct an appropriate tailored protocol for e-health applications irrespective of their values in the parameter hyper-space.

Intelligent construction of communication protocols is achieved by adopting the Analytic Hierarchy Process (AHP) formalism, which is one of the most popular methods of Multicriteria Decision Making (MDM). The AHP formalism, originally proposed in (Saaty, 1977), has been successfully applied in solving real world problems in different areas such as in Sports, Medicine, Management Science and Computer Science. The capability to handle subjective criteria and inconsistencies in the decision-making process and the conceptual simplicity of that method are the major reasons of its popularity.

The AHP method has three major components.

1. *Structuring the hierarchy*, thus determining the relative criteria and alternatives (see Figure 1). To this end, the first level of the hierarchy is used to denote the overall objectives or goals of the decision problem.

The second level is occupied by criteria for assessing the accomplishment of the objectives, while the third level contains available actions or alternatives.

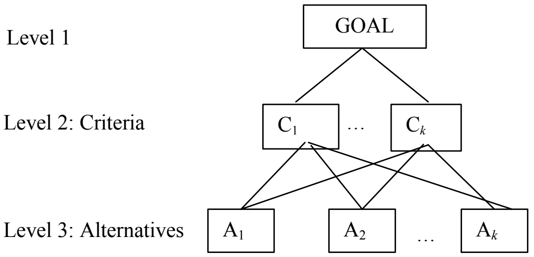


Figure 1. The Analytic Hierarchy Process.

2. *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:
   2.1 Determine the relative importance of the criteria
   2.2 Determine the relative standing of each alternative with respect to each criterion.
3. *Synthesis of preference weights* to yield composite priorities for alternatives.

Following the AHP, (Saaty, 1980), in Step 2.1 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 Eigenvalue method (Triantaphyllou. and Lin, 1996), the Logarithmic Least Square method (Triantaphyllou. and Lin, 1996), the Goal Programming method (Bryson, 1995) or the Fuzzy Programming method (Mikhailov and Singh, 1999a).

In Step 2.2, 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 of the methods described in (Triantaphyllou. and Lin, 1996; Bryson, 1995; Mikhailov and Singh, 1999a). 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 user and QoS judgements 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 judgment matrices. Thus, a weight determination technique suitable to handle inconsistencies is indispensable, as will be explained below.

Finally, in Step 3, 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:

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

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

The dynamic nature of our problem requires the use of a weight determination technique able to handle inconsistencies. Therefore, the Fuzzy Programming Method (FPM), capable of solving even high inconsistent matrices, was used (Mikhailov and Singh, 1999b).

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. Mikhailov and Singh (1999b) show that FPM is able to produce better results than other methods when inconsistencies are high.

Usage of the FPM enables judgements to be expressed either as crisp, intervals or fuzzy numbers. Each reciprocal pairwise comparison matrix, $A=[a_{ij}]\in\Re^{p\times p}$, can be represented as a system of $m = p(p\text{-}1)$ linear equalities:

$$\mathrm{R}w = 0, \qquad (2)$$

where n is the number of elements compared, w is the vector of priority weights and $\mathrm{R}\in\Re^{p\times p}$. 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 programming problem that can be easily formulated and solved as a standard linear programming problem:

$$\begin{aligned} &\text{Obj.: } \max \lambda \\ &\text{s.t. } \lambda d_k + \mathrm{R}_k w \le d_k,\ k = 1,\dots, m,\ 1 \ge \lambda \ge 0 \\ &\qquad \sum_{i=1}^{p} w_i = 1\ ,\ w_i > 0,\ i = 1,\dots, n, \end{aligned} \qquad (3)$$

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 for all these parameters, d_k, to be set equal (Mikhailov and Singh, 1999a). The optimal solution to the problem (3) is a vector (w^*, λ^*), whose 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.

Intelligent Protocol Management

We have integrated the DRoPS framework for construction of adaptable, tailor-made protocols with the AHP formalism into an architecture able to intelligently manage user requirements, bearing in mind the dynamically fluctuating QoS. The diagram of this architecture is given in Figure 2 and shows how both monitored QoS and user choices impact on the construction of the judgement matrix, which serves as the basis for the AHP to suggest a suitable protocol stack configuration under DRoPS ensuring that user requirements are maintained at an optimum level (Ghinea and Magoulas, 2001). This contrasts to traditional legacy protocols stack such as TCP/IP and UDP, which make no allowance for user - related considerations in their functionality.

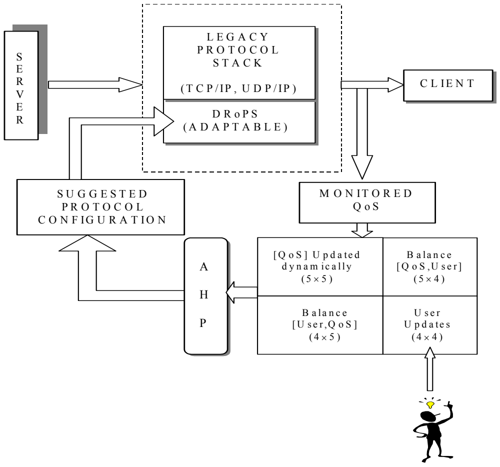
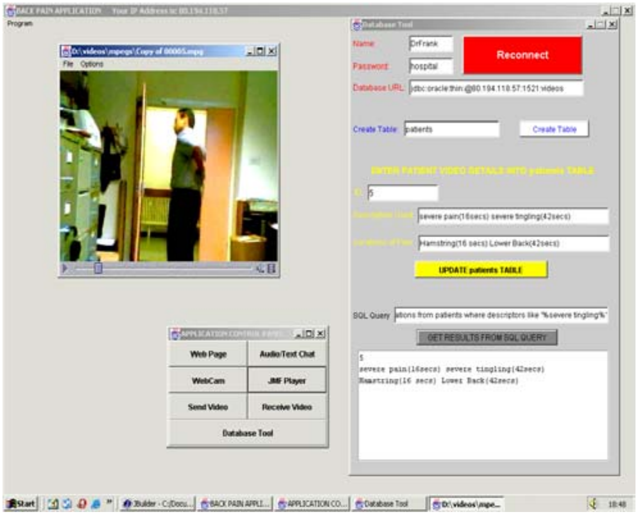


Figure 2. Intelligent architecture for protocol management

In its existing form, our architecture uses the FPM described above to solve a nine criteria and nine alternatives communication protocol construction problem. In our approach, the end-user interacts in the evaluation of the criteria judgement matrix. In particular, the judgement matrix consists of three parts: one dealing exclusively with user issues, one solely with QoS judgements, whilst the last reflects the balance between user and QoS considerations (Figure 2). As mentioned above, within our framework, each multimedia application can be characterised by the relative importance of the video (V), audio (A), textual components (T) and its dynamism (D). At this point, it should be mentioned that the user part of the judgement matrix is the only part evaluated by the end-user according to his preference regarding his/her priorities attached to the four components considered in our model. In the QoS part, five network level QoS parameters are considered: BER, SL, SO, DEL and JIT.

We have developed a distributed collaborative tool for back pain clinicians, a snapshot of which is given in Figure 3. 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. Moreover, the transmission of the multimedia data associated with the application adapts dynamically using the DRoPS framework, depending on network conditions and a set of predefined user requirements, as given by the architecture of Figure 2.



Name: DrFrank
Password: hospital
Database URL: jdbc:oracle:thin:@80.194.118.57:1521:videos
Create Table: patients
5
severe pain(16secs) severe tingling(42secs)
Hamstring(16 secs) Lower Back(42secs)
SQL Query: ations from patients where descriptors like '%severe tingling%'

```
5
severe pain(16secs) severe tingling(42secs)
Hamstring(16 secs) Lower Back(42secs)
```

Figure 3. E-collaboration system for back pain treatment

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.

	BER	SO	SL	DEL	JIT	V	A	T	D
BER	EQI	SLI	SLI	**DLI**	ELI	EQI	EQI	EQI	EQI
SO	SMI	EQI	EQI	**DLI**	SLI	EQI	EQI	EQI	EQI
SL	SMI	EQI	EQI	**DLI**	SLI	EQI	EQI	EQI	EQI
DEL	**DI**	**DI**	**DI**	**EQI**	**DI**	**DI**	**DI**	**DI**	**DI**
JIT	EI	SMI	SMI	**DLI**	EQI	EQI	EQI	EQI	EQI
V	EQI	EQI	EQI	**DLI**	EQI	EQI	ELI	WLI	SLI
A	EQI	EQI	EQI	**DLI**	EQI	EI	EQI	SMI	SMI
T	EQI	EQI	EQI	**DLI**	EQI	WMI	SLI	EQI	EQI
D	EQI	EQI	EQI	**DLI**	EQI	SMI	SLI	EQI	EQI

Table 2. Matrix describing the relative importance of QoS and user parameters for high network delay scenarios

Table 2 reflects the situation where high levels of delay were detected on the network. Table 3 details the overall priority values when delay is *"demonstrably important"*.

Micro-protocol	Overall Score
micro1	0.1525
micro2	0.1383
micro7	0.1342
micro4	0.1263
micro2	0.1198
micro9	0.0915
micro6	0.0887
micro5	0.0833
micro8	0.0654

Table 3. Ranking order and priorities of microprotocols.

By analysing the results of Table 3, one can see that the first ranked micro-protocol is indeed able to best handle the respective networking scenario. Thus, the "*no sequence control"* micro-protocol, (micro1), because of its streamlined functionality, is the protocol which introduces the least amount of delay in the transmission of multimedia in the DRoPS framework.

Conclusions

We have presented a intelligent mechanism of obtaining, in the context of a distributed collaborative e-health multimedia application, 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.

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