In... ...ment

...will inevitably depend on their ...etworks However, although the ...erspective of the experience as ...tegrated viewpoint. To alleviate ...er for obtaining a priority order ...at user-level Quality of Perception is maintained at ...chnical concerns with user perceptual considerations ... multimedia communication protocols. The proposed ...s not only classical networking considerations, but, ...opens the possibility for such protocols to dynamically ...erences.

..., Quality of Perception, Quality of Service, Multi Criteria

...nt care using advanced multimedia techniques aim to offer users ...ve communication pathways, using Internet-based, interactive ...of telecommunications and information technology in the health

...s traditionally been characterised using Quality of Service (QoS) ... current distributed multimedia applications are built either do not ...rt service) or specify them in terms of traffic engineering parameters ...ever, these parameters do not convey application-specific needs such as ...mational load on the stakeholders. There is thus an architectural gap ...S and application-level user-centric requirements of the distributed ...tributed multimedia systems to inefficiently use network resources and ...ch in turn has a direct negative impact on the stakeholder experience of

... bridge the user-network gap by employing an intelligent decision making ...le transmission protocols, specifically tailored for the transmission of medical ...paper is as follows: the next section introduces issues relating to back pain relevant to our work. The subsequent section presents the framework for adaptation used in our approach. Lastly, an application example is provided and concluding remarks are drawn.

BACK PAIN

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 [1]. 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 [1]. 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 [2]. 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 [3]. Moreover, back pain does not affect solely the adult population: studies across Europe [4] 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" [5]. 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 [2]. 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 [6],[7]. 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 Figure1. have been successfully used in pain centres for over 45 years [8] 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 [7]. 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 [9].

INTELLIGENT TRANSMISSION OF BACK PAIN DATA

In the UK, 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. We are currently developing BPDRoPS, a distributed tool for remote e-collaboration in the treatment of back-pain. This tool, used by practitioners and patients alike comprises a two-way video link (over which interactions between the back-pain consultant, at one end, and GPs, physioterapists and/or patients, at the other, take place), a shared text box in which participants may specify various textual input (e.g. medication, details of rehabilitative exercises), as well as a further subwindow containing the details of the back-pain drawing as filled out by the patient. Moreover, BPDRoPS also integrates a repository of back-pain data, which can be accessed by either participant to the remote diagnostic session, a snapshot of which is given in Figure 2. BPDRoPS thus transmits video, audio, text and graphic content across inherently unreliable telecommunication networks. If this is done without regard for perceptual requirements, then chances are that transmission will be an ineffective, resource-consuming exercise, fraught with problems affecting multimedia transmission in general, such as delay, jitter and loss, and with consequently little take-up by stakeholders.

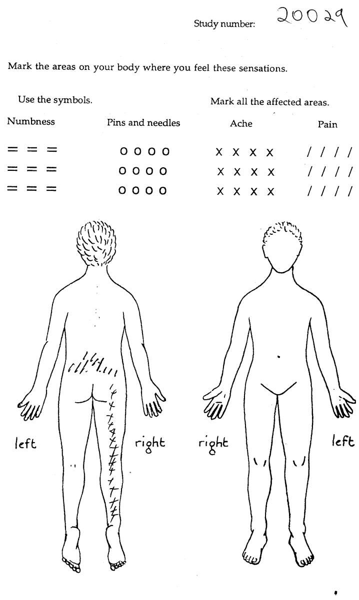

Figure 1: Pain drawing.

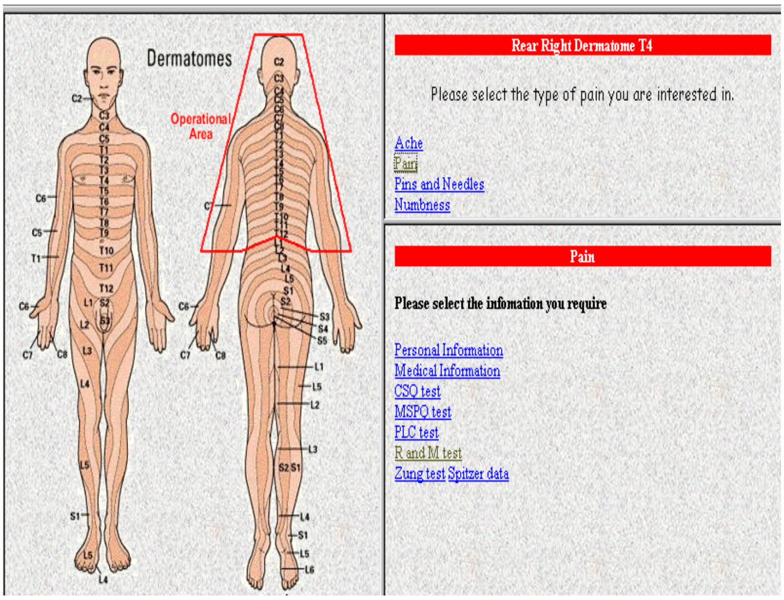

Figure 2: Back pain data management in BPDRoPS.

QUALITY OF PERCEPTION

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

1. 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.
2. the service 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 [10],[11], 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.

A FRAMEWORK FOR QoP ADAPTATION

Distributed guaranteed services need to incorporate capabilities for responding to QoP and QoS changes originating from the user/applications or the system/network. To achieve these changes, the networked multimedia system will require fast renegotiation protocols and adaptive mechanisms. The renegotiation protocols will rely on dependable and simple monitoring and recognition algorithms to detect requests for QoS changes or system degradations. The envisioned adaptive mechanisms should include update mechanisms for resource allocation in response to detection of system degradation. The challenge will be to make monitoring, detection and adaptation mechanisms efficient and fast.

The BPDRoPS tool is based on our previous work on the *Dynamically Reconfigurable Stacks Project* (DRoPS), which provides an infrastructure for the implementation and operation of multiple adaptable protocols [12]. The 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 (to smooth out bursts in traffic), at the user or interface level, and transmission queue scheduling, at the device queue level.

BPDRoPS-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 BPDRoPS 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. For instance, an acknowledgement protocol can be implemented either as an Idle Repeat Request or a Per Message Acknowledgement Scheme.

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.

CONSTRUCTION OF COMMUNICATION PROTOCOLS IN BPDRoPS

In our work, transmission of back pain data incorporates intelligent decision-making mechanisms constructed using the Analytic Hierarchy Process (AHP), which is one of the most popular methods of Multi-criteria Decision-Making (MCDM). To this end, we have applied Saaty's (AHP) formalism [13] to obtain a method which, from combined user-, application- and network-level requirements, ultimately results in a protocol configuration specifically tailored for the respective user-needs. Our approach links perceptual considerations with low-level technical parameters, taking into account the end-user. Thus, within the QoP framework presented above, a BPDRoPS session can be characterised by the relative importance of the video (*V*), audio (*A*) and textual (*T*) components as conveyors of information. This is in accordance with experimental QoP results obtained which emphasise that multimedia QoP varies with: the number of media flows, the type of medium, the type of application, and the relative importance of each medium in the context of the application. Moreover, five network level QoS parameters have been considered in our model: bit error (*BER*), segment loss (*SL*), segment order (*SO*), delay (*DEL*) and jitter (*JIT*). Together with the *V*, *A*, *T* parameters these constitute, in AHP terminology, the *criteria* on the basis of which an appropriate tailored communication protocol is constructed. In BPDRoPS, the functionality of this protocol is realised through a number of 9 microprotocols, spanning 4 broad functionality classes [10],[11].

Saaty's methodology results in the construction of nine matrices. Eight of these matrices give the relative importance of the various microprotocols (*alternatives*, in Saaty's vocabulary) with respect to the criteria identified in our model, while the last of these matrices details *pairwise comparisons* between the criteria themselves.

$$A_{BER} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1/3 & 1/7 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1/3 & 1/7 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1/3 & 1/7 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1/3 & 1/7 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1/3 & 1/7 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1/3 & 1/7 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1/3 & 1/7 \\ 3 & 3 & 3 & 3 & 3 & 3 & 3 & 1 & 1/5 \\ 7 & 7 & 7 & 7 & 7 & 7 & 7 & 5 & 1 \end{bmatrix} \quad (1)$$

The formulation of the nine matrices has been based on QoP results described in [10]. An example of one of the former type of matrices, i.e. of the different alternatives with respect to one of the criteria (bit error rate in this case) is given in Relation (1). Each entry a_{ij} of the matrix A_{BER} defines the numerical judgement in comparing criterion to criterion.

Psychological experiments have shown that individuals cannot simultaneously compare more than 7 objects (±2) [14]. Thus, usually, pairwise comparisons are quantified by using a scale of nine grades, which describe the relative importance of the criteria [13]. If a_{ij} is a point on this nine-point scale, i.e. $a_{ij} \in \{1,2,3,...,8,9\}$, then $a_{ji} = 1/a_{ij}$ also holds [13]. For example, in Relation (1) the judgement *"microprotocol A is equally important as microprotocol B with respect to BER"* corresponds to a weighting of $a_{ij} = 1$, while the judgement *"microprotocol A is absolutely more important than microprotocol B"* would correspond to a value of $a_{ij} = 9$. Intermediate terms can also be assigned when compromise is needed between two adjacent characterisations. Note that in Relation (1), the considered microprotocols are, in order {*no sequence control, strong sequence control, no flow control, window-based flow control, IRQ, PM-ARQ, no checksum algorithm, block checking, full Cyclic Redundancy Check*}. For example, as far as bit error rate is concerned (see Relation (1)), the only microprotocols that have an impact upon it are the checksum algorithms. The strongest of these methods, the full CRC, has the highest weight (a value of $a_{ij} = 7$) in comparison with all the others, while a relatively weak block checking algorithm is considered to be *moderately more important* (α_{8j}=3, j=1,2,…,7) than microprotocols from other functionality classes.

While all the previous eight matrices considered have a constant form, the matrix of each criterion with respect to all the other criteria named *C*, shown below, is the only one whose values may fluctuate as a result of changes in the operating environment, as well as a consequence of changes in *user preferences* and *perceptions*. Relation (2) provides an instance of this matrix used in our model; the respective criteria are, in order, *BER, SO, SL, DEL, JIT, V, A,* and *T*.

$$C = \left[\begin{array}{ccccc:ccc} 1 & 1/2 & 1 & 1/4 & 1 & 2 & 4 & 4 \\ 2 & 1 & 1 & 1/4 & 1/3 & 5 & 4 & 5 \\ 1 & 1 & 1 & 1/3 & 1/2 & 4 & 6 & 4 \\ 4 & 4 & 3 & 1 & 5 & 6 & 7 & 6 \\ 1 & 3 & 2 & 1/5 & 1 & 4 & 6 & 6 \\ \hdashline 1/2 & 1/5 & 1/4 & 1/6 & 1/4 & 1 & 1/2 & 3 \\ 1/4 & 1/4 & 1/6 & 1/7 & 1/6 & 2 & 1 & 3 \\ 1/4 & 1/5 & 1/4 & 1/6 & 1/6 & 1/3 & 1/3 & 1 \end{array}\right] \tag{2}$$

An average user, though, would have difficulty in *a priori* judgement of varying technical parameters such as delay, jitter, error and loss rates on highly subjective attributes such as perception, understanding and satisfaction. Whilst this is true for QoS attributes at the level of the transport service, users are better able to quantify their requirements in terms of more abstract characteristics like the prioritisation of core multimedia components such as *V*, *A* and *T*. The matrix *C* reflects this situation and could conceptually be split-up into 4 sub-matrices, which are:

- A 5×5 matrix, in the upper left part of the matrix in Relation (2), giving the relative importance of the *BER, SO, SL, DEL* and *JIT* criteria with respect to one another. This matrix changes dynamically during the course of the transmission of a multimedia clip. An example illustrating this behaviour is presented below.
- A 3×3 matrix, located in the bottom right of the matrix given by (2). Here, user input can reflect personal choices of the relative importance of the video, audio and textual components in the context of the application, as well as a relative characterisation of the dynamism of the multimedia clip. Whilst, these values can be changed dynamically depending on the visualised scene, *a priori* values in this case could reflect the result of user- consultations, such as those conducted in our original QoP experiment [10].
- A 5×3 matrix and a 3×5 (one of which is the transpose of the other) which reflect designer choices of the relative importance of the five QoS parameters considered on *V, A,* and *T.* The elements of these matrices remain fixed at run-time, and, in our particular case, reflect the results of our previous work on QoP [10].

Following the AHP, the weights w_i, i=1,…8 denoting the relative importance of each criterion i among the p criteria (p=8) are evaluated using the formula:

$$w_i = \frac{\left(\prod_{j=1}^{p} a_{ij}\right)^{1/p}}{\sum_{i=1}^{p}\left(\prod_{j=1}^{p} a_{ij}\right)^{1/p}} \quad i = 1,2,...,p \tag{3}$$

and a higher priority setting corresponds to a greater importance. 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. As previously, there is a total of p pairwise comparisons in the matrix and weights are calculated following Relation (3). The weighted sum model, [15], 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*:

$$P_j = \sum_{i=1}^{p} w_i \cdot w_{j,i} \tag{4}$$

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

Due to the dynamic nature of our problem, where the technical information and the perceptual information could form inconsistent judgement matrices, the need to apply a weight determination technique suitable to handle inconsistencies was indispensable. Therefore, the Fuzzy Programming Method (FPM), which is a method capable to solve even high inconsistent matrices, was used. The FPM proposed by Mikhailov and Singh [16] is an approach capable to handle inconsistent pairwise comparison judgement matrices, where the judgements can be expressed either as crisp, intervals or fuzzy numbers. Each reciprocal pairwise comparison matrix, $A=[\alpha_{ij}]\in\Re^{n\times n}$, can be represented as a system of $m = n\times(n\text{-}1)$ linear equalities:

$$\mathrm{R}\times w = 0, \tag{5}$$

where n is the number of elements compared, w is the vector of weights and $\mathrm{R}\in\Re^{n\times n}$. For the inconsistent cases, the method is finding a solution that approximately satisfies Equation (5), i.e. $\mathrm{R}\times \mathrm{w} \approx 0$.

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 program:

$$\begin{aligned} &\text{Obj.: } \max \lambda \\ &\text{s.t. } \lambda \mathrm{d}_k + \mathrm{R}_k w \le \mathrm{d}_k,\ \ k = 1,\ldots, m,\ \ 1 \ge \lambda \ge 0 \\ &\sum_{i=1}^{n} w_i = 1\ ,\ \ w_i > 0,\ i = 1,\ldots, n \end{aligned} \tag{6}$$

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 [16],[17].

After deriving the underlying weights from the comparison matrices through the FPM technique, the local weights are synthesised following the weight-sum model. The overall value V_j of each j^{th} alternative, A_j, is expressed as:

$$V_j = \sum_{i=1}^{n} w_i r_{ij} \tag{7}$$

where w_i is the weight assigned to the i^{th} criterion and r_{ij} is the relative score of the alternative *j* on criterion *i*. Obviously, the alternative with the maximum overall value V_j will be chosen.

The diagram of our architecture is given in Figure 3 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 BPDRoPS ensuring that user QoP is maintained at an optimum level [11]. This is in contrast to traditional legacy protocols stack such as TCP/IP and UDP, which make no allowance for user -related considerations in their functionality.

APPLICATION EXAMPLE

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 I: Overall values of the alternative microprotocols for the experiment

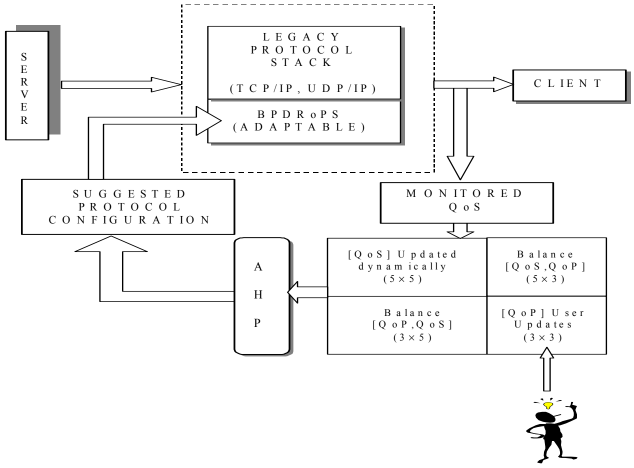

Figure 3. AHP-based architecture for QoP management

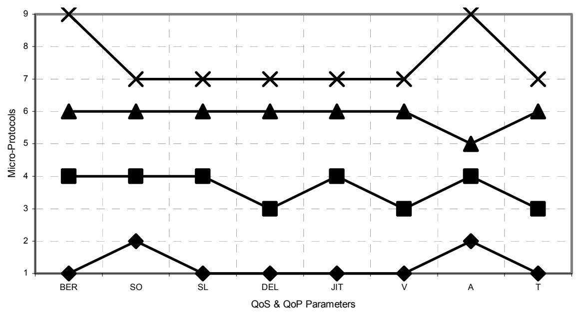

Figure 4: Resulting BPDRoPs protocol stack when QoS and QoP parameters are, in turn, of primary importance.

In Table I, our methodology has been applied to a situation where BPDRoPs is experiencing protracted delays due to network congestion. The notation adopted in Table I 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).

As a result of a delay-intolerant audio transmission being subjected to a period of high network delays, the upper left sub-matrix of Relation 2 can reflect this situation by changing the numerical judgements to reflect a more radical bias in favour of the delay component. In Table 1 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 4, we show the resulting protocol stack which is constructed using our approach in the BPDRoPS framework, when each of the QoP and QoS parameters becomes, in turn, of primary importance. 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. Thus, in the case where segment loss (SL) is of primary importance then, as can be seen from Figure 4, the BPDRoPS 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 BPDRoPS 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.

Similar observations apply in the case when QoP parameters are of primary importance. Accordingly, all media component 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 distributed multimedia applications 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.

CONCLUDING REMARKS

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 addressed the problem of bridging the application-network gap, in a remote collaborative environment for back pain treatment, from a multi-attribute decision-making perspective. To this end, we have used the Analytic Hierarchy Process to integrate Quality of Perception- related requirements with the more technical characterisation of Quality of Service. We have shown how our framework is capable of suggesting appropriately tailored transmission protocols, by incorporating human-perceptual requirements in the remote delivery of e-health solutions.

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