Metadata Modeling for Quality of Service Management in Distributed Multimedia Systems[1]

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Abstract

In distributed multimedia systems, since multimedia objects are voluminous and unstructured, manipulation, transfer and visualization of such objects can require a lot of time and resources. It then becomes essential to prevent unsatisfactory information delivery. For that purpose, Quality of Service (QoS) management appears as an essential function supplied by distributed multimedia systems to provide the user the pertinent information with the required quality and efficient access. This function aims to control and guarantee the level of quality that the system is able to offer to the user. Providing this function requires the design and the implementation of a system database that stores and manages the metadata required for QoS management.

We have created concepts and developed methods for managing the resources needed for QoS negotiation and adaptation in an adaptive distributed environment. The QoS manager we have prototyped is based on a metadata database which is in charge of managing all the QoS information required for QoS negotiation and adaptation. In this paper we follow an object-oriented approach to present metadata modeling for quality of service management in distributed multimedia systems. We identify the actors of the QoS negotiation protocol and present a conceptual model for QoS metadata associated with each of them. We prove the relevance of metadata for Quality of Service management while illustrating how QoS metadata is used during the different steps of the negotiation and adaptation protocol.

1. Introduction

Distributed multimedia systems require the integration of various services for multimedia object creation, storage, access, transfer and presentation [1]. Such systems integrate different components among which the database system plays a dominant role in providing a persistent and reliable environment to store and access multimedia objects.

Information stored in the database can be divided into two categories:

- multimedia information: the objects stored and accessed by the applications,

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- metadata, allowing the system to efficiently access, transfer or display multimedia objects .

Research in the field of multimedia databases has essentially focused on the first category and led to various propositions for multimedia data modeling [10], for data manipulation languages [3] as well as for strategies for multimedia object storage [13]. Recently Klas and Sheth [9] have brought to the fore the necessity of defining and efficiently managing metadata within the framework of distributed multimedia systems.

Metadata required for the management of multimedia objects are generally classified into five categories [2]: metadata about the representation, the structure, the content, the storage and the versions. Metadata about the representation is qualitative and quantitative information related to the mode of representation of multimedia objects. In this category we find format, coding and compression techniques as well as characteristics associated with these techniques. Metadata concerning the structure describes the components of multimedia documents and the constraints defined among these components. This category includes the description of the composition hierarchy as well as spatial and temporal constraints required for the document display. Metadata about the content describes the content of multimedia objects. This information can be automatically extracted, for example index terms in a book; alternately, it can be defined by a user while placing the objects in the database. This category also includes information used for document classification. Metadata concerning storage describes how, when and where multimedia objects are stored. This category includes information about the space required for storage as well as the location of objects in a distributed environment. Metadata about the document versions describes the evolution of multimedia objects as well as alternative versions of such objects.

In order to process a search request, the various components of the distributed multimedia system require the use of these categories of metadata. Metadata describing the content of multimedia objects is used in the multimedia document searching process to select pertinent documents. Metadata concerning the representation can be used for quality of service management, distribution management, and data administration. Much attention has been paid to the use of metadata for multimedia document searching, but less to its use with other functions of multimedia systems.

Among these functions, Quality of Service (QoS) management is essential to efficiently access pertinent information at the required level of quality. This function aims to control and guarantee the level of quality that the system is able to offer to the user. While integrating such a function in a distributed multimedia system, it is necessary to consider the user's requirements regarding the quality of service provided by the system. Such requirements may concern system performance such as the delay needed to transfer objects, the quality of information provided, e.g. image quality: black and white or color, as well as financial costs attached to document delivery such as the costs charged by a library to obtain a copy of a journal article.

In our more recent work, we have shown that all the components of a distributed multimedia system should be involved in the QoS management process [15]. The users should describe their requirements related to QoS, but these requirements must be adapted to the various constraints supported by the distributed multimedia system components: client machines, database systems, server machines and transport system.

Thus the QoS manager is in charge of managing all this information in order to provide the user with an offer which might satisfy his requirements. It then becomes essential to properly define the metadata needed for QoS management, to integrate them within the multimedia document model and to take them into account when processing a user's request.

The objective of this paper is to present metadata modeling for quality of service management in distributed multimedia systems. The paper is organized as follows: section 2 presents the QoS functions required in DMS. Section 3 describes the QoS metadata modeling. Section 4 describes metadata usage during the different steps of the negotiation protocol. Section 5 concludes and presents future work.

2. Quality of Service Management

The concept of Quality of Service (QoS) was originally introduced in computer communications to mainly characterize data transmission performance[5]. In distributed multimedia systems, considering QoS only at the communication level is no more sufficient. QoS is directly perceptible by the user who should have the possibility to express his requirements. QoS management then becomes an essential end-to-end functionality that the entire distributed multimedia system should provide [15].

In this section we present the problems faced while providing End-to-End QoS in distributed multimedia systems. We later focus on the approach we propose in our research project and then identify the QoS actors in this framework

2.1. End-to-End Quality of Service

Quality of Service management on an end-to-end basis means that: (1) the user expresses his wishes on the quality he wants and the cost he is willing to pay, and (2) the system transparently operates in order to deliver the requested level of quality. This approach requires to consider QoS not only at a specific layer, such as the network or the operating system layers, but at all the layers of the distributed multimedia system. Figure 1 positions QoS management across the different layers of distributed multimedia systems.

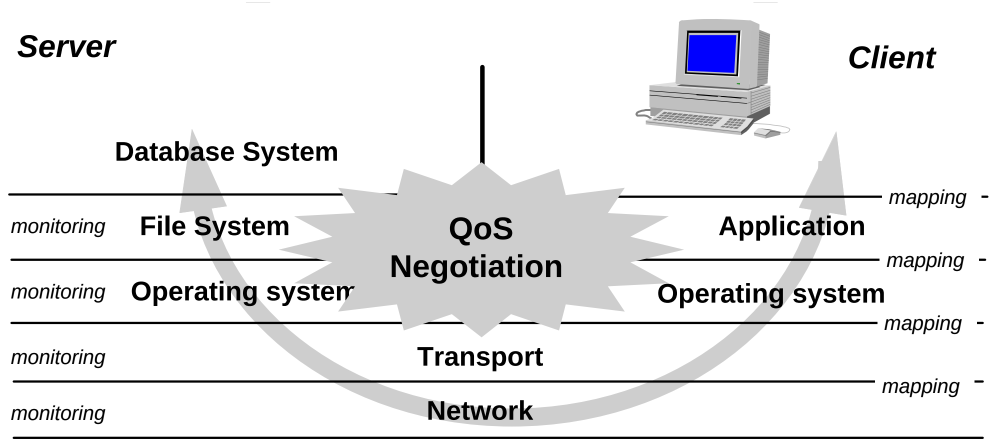

Figure 1: Multimedia System Layers and QoS management

Four different activities are identified in QoS management: specification, mapping, negotiation, re-negotiation and monitoring. QoS specification deals with the definition of the requested QoS level. This definition is made according to different dimensions such as time, cost or quality. It should be offered through an adequate interface allowing the user to express how he perceives the quality of the provided service. As an example, a user could express his QoS level as the following statement: " I am interested with full-color videos that could be delivered for less than 10$ and in a 40 s delay". QoS specification can be provided by the user or by the application programmers for a set of applications. In both cases a specification language is required[14].

QoS mapping occurs at the different layers of the multimedia system. User perceived quality has to be mapped onto QoS parameters that will be supported by the different layers. As an example, the previous statement must be translated into parameters values for resolution, frame rate and throughput.

QoS negotiation corresponds to setting up a contract between the different layers and components of the distributed multimedia system in order to satisfy the user's QoS requirements. This function is in charge of finding a system configuration that should support the requested QoS and can be considered as similar to resource allocation in distributed systems. QoS negotiation leads to a commitment from the overall components concerning the quality level that will be offered. Different types of commitment can be provided: guaranteed, best-effort or stochastic. In the first case, the different components must reserve the corresponding resources.

These three different steps constitute a simplified QoS processing model which is sufficient when a final agreement is found between the different components. Nevertheless, different situations can occur and lead to re-negotiation, that is to process again QoS specification and negotiation. Examples of such situations can be modifications on the initial user's requirements: "I do not want to wait more than 30s for information delivery" or a deterioration in the communication conditions such as a network congestion. In both cases, other steps for specification and negotiation are required.

To efficiently manage QoS in distributed multimedia system, a QoS monitoring function is essential. Its role is to examine the actual QoS level provided by the system components and to compare it with the initial requirements. When the initial requirements are not satisfied, the QoS monitor notifies the user or the application for an eventual re-negotiation decision.

The complexity of QoS processing, requires to systematically consider QoS in the different layers of distributed multimedia system. In the following sections we present the framework in which our research is conducted and we identify the actors of QoS management we have introduced.

2.2. Our Project

In the framework of the "Broadband Services" project of the Canadian Institute for Telecommunication Research [16] involving several Canadian universities, our sub-project especially investigates the impact of dynamically changing QoS on the design of applications and we develop methods for the management of the quality of service related resources within a distributed environment [8]. A multimedia news-on-demand service has been identified as the target application and provides the functional requirements for the project [7].

With the current prototype, the user may choose a document in the database for presentation, and select the desired quality of service (QoS) including parameters such as video and audio quality, size of display, and cost. A graphical interface is available for this purpose which includes the possibility of obtaining examples of specific quality features. The transmission of the continuous media components of the document, e.g. video and audio, proceeds in real-time over ATM or a local network during the presentation of the document. The system allows for several variants of a given media component, possibly with different QoS parameters and accessible over different networks. The QoS negotiation and adaptation features allow for the selection of an optimal configuration for a given user request and for automatic adaptation in case of changes of the QoS system parameters, such as in case of network or server congestion.

Our approach is similar to the one proposed in [11] where the architecture uses a brokerage model which incorporates QoS translation, QoS negotiation and re-negotiation. In contrast to the previous approach where the system configurations considered are static, we propose a QoS management architecture that supports the dynamic choice of a configuration to support the QoS requirements of the user of a specific application [4]. We consider different system configurations and select an optimal one to provide the appropriate QoS support. Moreover, the service requested may be different from a data flow service, depending on the particular application.

2.3. Actors for QoS management

Our distributed multimedia system follows a multi-client multi-server architecture. The client offers search and access to the multimedia database and the server provides reliable storage for multimedia objects. Figure 2 illustrates the physical architecture of our distributed multimedia system. The server is composed of a database server that provides access to specialized file servers such as continuous media file servers or archival storage servers.

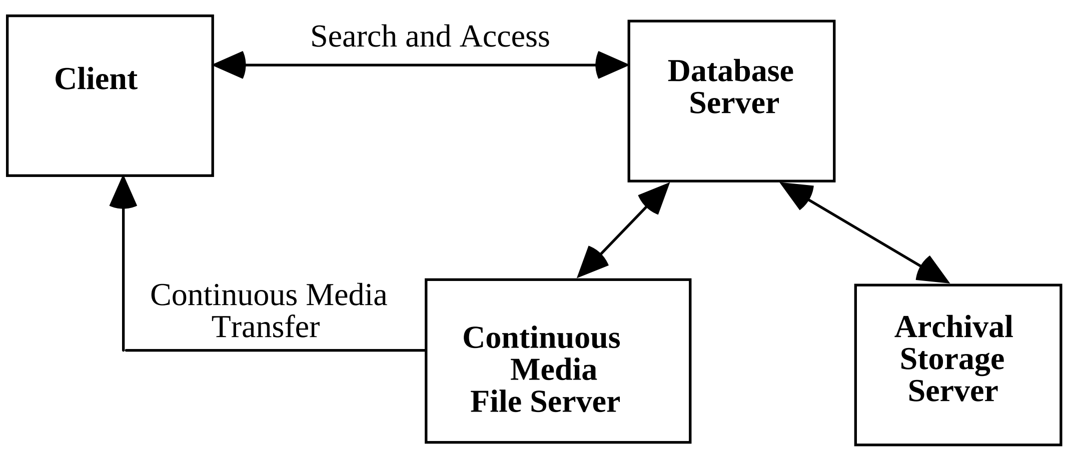

Figure 2: Physical Architecture

A QoS manager, supporting the previously defined QoS management steps, is implemented inside this architecture both on the server and the client sides. QoS management takes place during the different phases of the user's request processing: search, access and display. Figure 3 presents the functional view of our system in OMT object model notation [12], this view focuses on QoS management and shows the successive steps that are processed to deliver multimedia objects to the users. Ideally, QoS management should become completely transparent to the user. In this prototype this goal is achieved by QoS specification through the definition of QoS profiles. These profiles are defined for particular applications and users. At the beginning of the session, the user sets his preferred profile through the dedicated user interface. For the applications, we have defined an API allowing the specification of their behavior concerning QoS characteristics and management. That becomes the responsibility of application programmers to specify applications QoS requirements and their reaction to QoS modification or degradation.

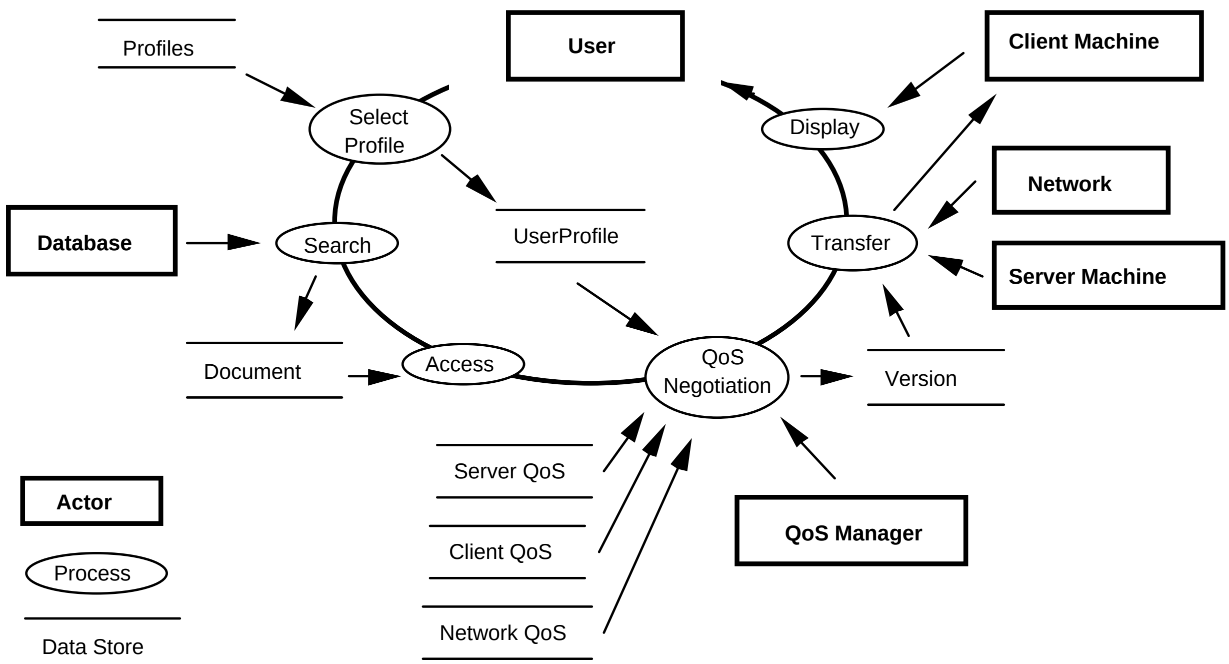

Figure 3: Functional View of QoS Management

While querying multimedia databases, we distinct two different phases: the *search* and the *access* phases. The *search* phase consists in isolating a set of documents of potential interest for the user. Among these documents only those specified by the user during the *access* phase will be completely delivered. These different steps are required to avoid the delivery of large amount of data that are not of real interest to the user. During the search phase, the information delivered to the user are the metadata describing the content of the document. These metadata allow the user to select the document he wants to access.

For the chosen multimedia document, the negotiation protocol is initiated to select the variant of each composed monomedia object that matches the requirements of the user given by his user profile and the constraints of all the involved actors. These constraints are identified for each actor by analyzing its QoS information. Some of the QoS parameters, such as the client machine environment are static, while other parameters are dynamic, such as the load of the server machine or the available memory resources. This information will be detailed in Section 3.

3. Quality of Service Metadata Modeling

In Section 1 we presented the various categories of metadata required for multimedia document management within the framework of distributed multimedia systems. These categories: representation, structure, content, storage and versions, group multimedia document characteristics that are generally used to search the multimedia database for pertinent documents. The QoS manager requires information from all these categories. Nevertheless, these categories are not sufficient for processing quality of service negotiation and re-negotiation. Besides the information associated with multimedia documents, the QoS negotiator needs information describing QoS constraints for the different system components involved in the negotiation. Thus the traditional classification of metadata should be reviewed in order to include QoS information concerning the user, the client machines, the server machines and the transport system. In this section we review metadata classification in integrating all the information required for quality of service management. We distinguish three categories of QoS information for: the user, the system components and the multimedia document.

3.1. User's QoS Information

In the previous sections, we have seen that the QoS specification activity provided in QoS management consists in the definition of the quality of service perceived by the user. In our system, we have implemented a user interface that helps the user while setting and modifying his requirements through user profiles.

A user profile describes user preferences in terms of (1) QoS settings for video, audio, still images and text, (2) cost he is willing to pay for a given quality, and (3) time constraints, such as the maximum delivery time. The user QoS setting is described in terms of a set of user-perceived characteristics for the performance of a service. The user profile also gives priorities between the three dimensions of QoS.

To avoid repeating the lengthy QoS parameters setting process, the user should be able to store QoS profiles. Then, while starting a new session he selects the desired profile. The user may display examples of varying quality in order to see if the profile is pertinent. A set of QoS parameters is associated to each type of monomedia, namely video, audio, text and image. Furthermore to specify the cost and timing constraints, a number of parameters are required. The profile manager provides a set of predefined user profiles that help the user in setting a new profile. A detailed presentation of the profile manager can be founded in [6].

3.2. System Components QoS Information

QoS parameters associated to system components describe the multimedia environment and its technical characteristics such as memory size, available formats, screen quality or system performance. They are associated to client machines, server machines and transport system. We here make a distinction between static and dynamic QoS parameters.

Metadata for static parameters describe the QoS static constraints associated with the system components and more specifically with the client and server machines. Information concerning the hardware available on the machine: screen and audio devices, and software supported by the machine: formats and compression techniques. The last parameter is concerned with the cost for accessing the machine.

screen device:	type of monitor (black and white or color) and its characteristics
audio device:	type of audio device and its characteristics
formats:	formats supported by the component
compression:	compression techniques supported by the component
costs:	costs required for accessing this component

During the negotiation process, and more specifically in the QoS monitoring phase, some parameters must be dynamically evaluated, more specifically for the transport system. These include throughput, transfer delay and guarantee. The guarantee indicates how the component will respect its QoS obligation: by providing its best effort or by guaranteeing it.

throughput:	throughput associated with the component
delay:	transfer delay
guarantee:	guaranteed or best effort
disk storage:	available space on the disk
costs:	costs of accessing and transferring data

QoS information describing the system components are used during QoS negotiation to set up a system configuration that will be used to transfer the multimedia documents selected by the users.

3.3. Document QoS Information

The multimedia documents are the objects transmitted to the user by the distributed multimedia system. These documents have intrinsic QoS characteristics used during the different steps of QoS negotiation. In the following, we explain the integration of QoS information in the abstract multimedia document model we have introduced in our project.

In this model, presented in Figure 4 using the OMT object model [12], a multimedia document is considered as either a monomedia document or a multimedia document. A multimedia document is composed of several monomedia objects usually synchronized with each other and possibly shared by different multimedia documents. The **Multimedia** entity is described by the aggregation link with **MonoMedia** documents and by the attributes that depict the spatial and temporal synchronization relationships between the associated monomedia. In addition, a multimedia document includes a *Price* and information allowing the expression of search conditions on the multimedia database. Search criteria are expressed on the *Registration* and *Description* attributes that are traditional descriptors such as keywords, author, date etc....

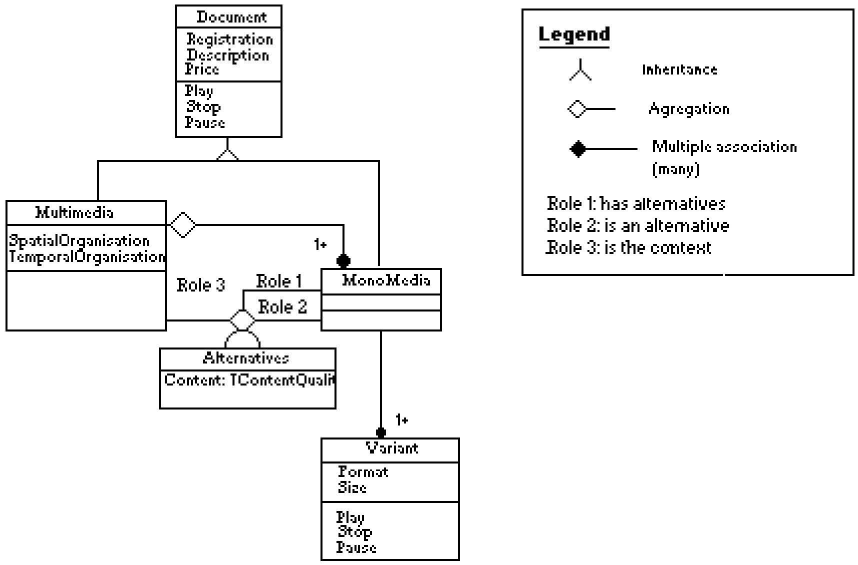

Figure 4: Class Hierarchy for Multimedia Documents

We assume that each monomedia may exist in different physical representations, called **Variants**, which are used by the negotiation protocol. A monomedia object is defined in a particular medium: a text, a still image, an audio sequence, a graphic, a video sequence or an audio-video sequence. Its variants are physical objects represented in the same medium but with different formats and quality. For instance, a same video sequence may exist in MPEG2 format and also in MJPEG format and under different resolutions. That allows some kind of replication for monomedia objects with different quality levels.

The quality of a given monomedia document is defined by static parameters depending on the kind of monomedia medium or referring to the physical localization of the element. They are specific to a variant, so they are stored in the variant inheritance hierarchy. For clarity reasons, this inheritance hierarchy is not shown on this figure. We can easily imagine that the **Variant** class is specialized into **Image**, **Text**, **Audio** and **Video** sub-classes. The QoS parameters give, for instance, the format of the coding, the size of the file, the color of a video.

In the model we have designed, we have introduced the concept of alternatives for monomedia objects. This concept allows a monomedia object to be substituted in the context of a given multimedia document by an other monomedia component, called *alternative*. This object may represent condensed or abstracted information and/or another medium in order to get documents at a lower cost. Such an alternative will be delivered when the QoS offer is not satisfactory for the original monomedia component. For instance, an alternative for a video sequence could be an audio sequence describing the same event or a portion of text describing it. The concept of alternative is introduced in our model through the ternary association between the Monomedia, Multimedia and Alternatives classes.

4. Using QoS Metadata

QoS management, and more specifically negotiation and adaptation, needs the different types of metadata that we have previously defined. In this paper, we position QoS management as a mechanism to examine the search space for a given request, and to provide the user with cooperative answers according to the quality dimension of his request. Figure 5 illustrates this approach. In that perspective, the document quality relevance to the query then becomes the main focus of QoS management.

In this section we examine the role of the QoS manager from a database point of view. In particular, we show that the different steps of QoS management aim at reducing or extending the search space for a given request on the multimedia database. We first describe how the search space is identified for a given request and later we examine the search space reduction and extension during the negotiation and re-negotiation phases.

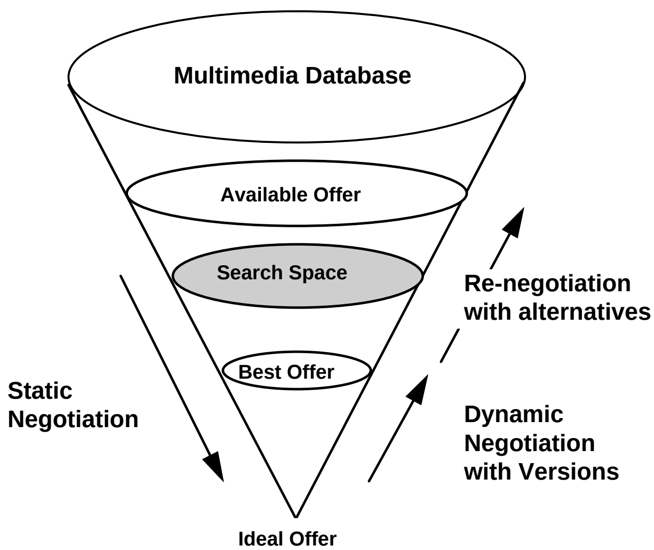

Figure 5: QoS Management as Operations on Search Space

4.1. Initializing and Identifying the Search Space

Querying distributed multimedia databases cannot be provided as usual database querying strategies provided for example by relational database systems. In particular, several steps must be defined in multimedia documents retrieval: initialization of the querying environment, searching to isolate potential documents and last, display of the pertinent documents.

In a distributed environment the initialization phase can be dedicated to the selection of sites or information providers that have the preference of the user. This can be done using profiles for information provider preferences such as the bookmarks found in the World Wide Web.

This initialization step must then be seen as the set up of the user environment concerning preferred information providers as well as quality of service requirements. In our present prototype, we focused on QoS specification, that is the QoS user's preferences set up. This is done through the selection of a current profile in the set of user defined or pre-defined profiles. The user interface allowing the profile definition follows a quality by example approach [6].

The initialization step is directly followed by the search phase of the request. This phase consists of the pre-selection of a set of multimedia documents of potential interest for the user. This set of multimedia documents is built according to some search criteria expressed by the user. An example of a search request can be: "Select all the multimedia documents talking about the last film of Clint Eastwood". The identification of the search space is processed by the database system in selecting the documents according to criteria expressed on content description metadata such as keywords, author or date. This step aims at giving the user all the information he needs to choose the multimedia documents he wants to display. The main preoccupation is then to minimize the volume of transferred data. In the current prototype, this steps builds as result, all the metadata on the content of the document as well as the metadata required for QoS negotiation. This set of metadata consists of the structure of the multimedia objects and the set of QoS parameters for each of their components.

4.2. QoS Negotiation or Search Space Reduction

Among the set of multimedia documents that are of potential interest to the user, some of them do not offer the required quality level but perhaps a better or reduced level. At this step two alternatives appear. The first one consists in presenting to the user the metadata of all potential multimedia documents, without considering their QoS characteristics. The second one consists in reducing the search space by filtering the set of documents to present only those offering the required level or a lower level of QoS.

The first alternative is optimistic in the sense that the user should see the largest set of documents and can decide to change his QoS requirements if necessary. This corresponds to user-oriented QoS management. The second alternative supposes that the requirements expressed by the user cannot be changed. This one is more application-oriented and supposes that the user has not a lot of scope to act.

In our current prototype, where we mainly focus on user-oriented QoS management, we did favor the first approach. We are presently defining a mixed approach that would organize the search space. This approach consists in sorting the set of potential documents according to the user's QoS requirements and the priority of each quality dimension: time, cost and quality.

All the QoS information collected during the search space identification and reduction steps are static metadata describing the quality of the documents. They are essential but not sufficient to process QoS negotiation. After having reduced the search space, and as soon as the user asks for accessing a document, the QoS manager initiates negotiation in order to set up a transmission contract satisfying the required QoS level. This phase implies (1) to determine the variants of the monomedia objects that will be transferred and (2) to set up the required system configuration, that are the components involved in the transfer. For the multimedia document the user wants to access, for each monomedia object component, the QoS manager identifies the best variant. According to these variants, the QoS manager evaluates dynamic QoS parameters such as resource availability or system load and determines the components and corresponding resources that are requested for the transfer. Once the negotiation is completed successfully, the content of the multimedia object is transferred to the client for display.

4.3. QoS Re-negotiation or Search Space Extensions

When negotiation is not successful, or when dynamic changes occur in QoS specification and conditions, adaptation or re-negotiation are required. Adaptation consists of an automatic re-configuration of the system without the user's intervention while re-negotiation leads to a new step for QoS specification. Both of these QoS activities involve exploring the search space to provide the user with an alternative offer that will satisfy the different constraints. This exploration consists in (1) examining the different variants that were associated to monomedia objects of the multimedia document and (2) examining alternatives of monomedia objects when a satisfying offer cannot be provided with the set of variants.

In both cases, the system will react according to the user's or application environment. For that purpose, the set of QoS profiles defined for a user is essential. Among the different profiles he defines, the user sets up several QoS levels he could accept: the desired QoS level, the acceptable QoS level and the worst QoS level. These different levels in the specification are used by the QoS manager to extend the search space. The user should have also the possibility to specify for which QoS level he wants to be notified by the system, that means when the system proceeds adaptation and when a re-negotiation step is necessary.

QoS management can then be considered as a mechanism that explores the search space for a user's request according to the quality dimension. The different steps of QoS management lead to search space reductions or extensions using the concepts of variants and alternatives.

5. Conclusion and Future Work

In this paper we have presented our approach for QoS metadata modeling and usage in distributed multimedia systems. We have specified the QoS parameters we have integrated in our system. This specification has been validated in our first prototype and has shown the necessity of managing and accessing effectively the QoS metadata during the steps of the negotiation protocol. We have presented QoS management as a mechanism for exploring the search space according to the quality dimension of the request. We are currently working on the enhancement of our model for variants, alternatives and distribution in order to take into account semantic rules for the optimization of database access.

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