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QoS management for MPEG-4 flows in wireless environment

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Abstract

QoS represents one of the most crucial issues as it involves many different aspects and directly impacts the user satisfaction. In this paper we will tackle the very complex and challenging issue to develop a comprehensive architecture to allow mobile wireless user to access MPEG-4 flows while moving and at a given level of QoS. We will assume that network resources are managed according to the Grid paradigm, and that mobile agents are the underlying technology to implement coordination and communication mechanisms.

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1. Introduction

During the last few years, wireless devices have become more and more widely adopted, due to the users' needs for mobility and information anywhere and at any time [11,13]. Mobility poses new and challenging issues to be solved, among which QoS management is one of the most crucial, due to the immediate consequences it has on the user's satisfaction.

In the development of a powerful infrastructure which has to be able to provide services (with guaranteed quality, taking care of the user's profile, the characteristics of the mobile devices, and the available resources), the wired and the wireless parts are not as much separated as it may appear, but a strong coordination between such two environments is requested. Grid [3,5] is a valid solution to implement distributed management strategies in the wired part of the system, which have to strongly interact with the mechanisms available in the wireless part in order to guarantee more and more sophisticated services with a high level of QoS.

In this paper we will show how one can benefit from the use of the mobile agent technology, in order to manage the user's mobility in a simple and powerful way [13].

Thus, our view consists of mobile users who - while roaming from a cell to another - access multimedia services

(in our case an MPEG-4 flow [1]) provided in the wired area through computation and storage servers, coordinated according to the Grid paradigm.

2. QoS Management in wireless systems

Providing QoS means being able to guarantee the user with an accurate estimation of the time the information will take for arriving, of the information that will be lost, and of the level of throughput that can be achieved.

Assuring a mobile user with a determined QoS implies new issues, which are linked to the user's mobility, to the shortage in bandwidth resources, and to the high loss of information, which is typical of the wireless connections. The resources of a wireless connection may suddenly change, due to physical obstacles between the user and the access point, due to the weather conditions. They may also change because a user moves to a cell that cannot assign any resources to him/her. The issue of wireless networks is therefore the possibility of anticipating which cell will be occupied by the user, as well as designing adequate mechanisms that can react to the user's movements. Proactive and Reactive approaches are the techniques usually adopted. The proactive approach consists of trying to reserve the resources by anticipating the user's movements. This can be done through static and dynamic techniques. For instance, a static resource reservation strategy can be used with the proactive approach during

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the setup stage of the connection between the mobile user and the access point. However, this cannot be easily created, since a user cannot always know his/her movements exactly. The use of the proactive approach with dynamic techniques consists of trying to anticipate the next cell the user will move to, in order to reserve the resources dynamically only in the cells that are more likely to be visited [9]. Of course, this approach may mean that a cell may not contain resources to be allocated. In this case, the communication must be stopped. A dynamic algorithm of this type, which is based on the Position-assisted Bandwidth Reservation, and is called Predictive Mobility-Based Bandwidth Reservation Scheme (PMBBR) is described in [14]. The PMBBR is a modified version of the Mobility-Based Channel Reservation Scheme (MBCR) proposed by [6]. The PMBBR reserves the bandwidth in the cells next to the ones where the user is. This is done by analyzing position, speed and movement direction, and by using geo-location techniques based on an agent system.

The reactive approach is another dynamic technique for the management of the QoS. As the name suggests, we try to react to the user's mobility by allocating the resources again, each time the user moves. This means that when a new user enters a cell, the level of QoS for the other users decreases. If a new user cannot be accepted, the communication of the host coming into the cell is stopped. A system of reactive approach based on the communication between mobile users and access points is described in [14].

Furthermore, some 'hybrid' approaches exist, which try to balance the advantages and disadvantages of the reactive and proactive systems. They are called reactive-proactive approaches. As it is described in [14], two traffic classes can be defined in this system:

Class 1: The traffic belonging to this class will have a specific level of QoS. This will need to be respected, with the option of degrading the level up to a specific threshold, in order to avoid a considerable degradation in the service (real-time traffic).

Class 2: Two QoS levels (maximum and minimum) will be defined for the traffic belonging to this class. The gap between them will be very high. Thus, the traffic of this class will have no specific requests for QoS (non-real-time traffic).

Thus, two levels of QoS (lowest and highest) are fixed for each class and determined by the bandwidth allocated. The highest levels are the desired bandwidth, while the lowest levels are the minimum acceptable bandwidth. The main principle of this hybrid approach are prioritizing the Class 1 traffic instead of the Class 2 one, and the existing connections, which change the network access point each time, instead of the new connection requests. The solution proposed in [7] is similar to this hybrid approach. However, in this paper the algorithm proposed is based on the assumption that the user specifies the area he/she will

move to after establishing the connection (mobility specification), as it happens in the static Proactive Approach. The protocol used for the bandwidth reservation is an extension of the RSVP. It is called MRSVP and is described in [11].

3. Architecture

Since we think we cannot solve the issue of the QoS in a wireless context without considering the issues concerning the management of the QoS itself in a wired environment, in this section we are going to describe an entirely distributed reference architecture. The scenario we are examining consists of Wireless Area (mobile devices), Access Area (Access Point), Wired Area (Internet, Grid).

Our purpose is the definition of a middleware layer that allows the coordination of the different areas examined. The middleware environment is based on the mobile agent technology. The agent technology provides several advantages in the creation of a distributed and complex middleware environment such as the one we are considering, because of the high flexibility and autonomy, which are essential in the architecture proposed. This is due to the strict requirements in terms of transparency for the user, ability to operate in a heterogeneous environment, and the ability to adapt to the variations in the environment and to reconfigure dynamically. A software agent is a kind of software package that is 'smart' enough to act as an assistant to accomplish some tasks on behalf of human beings [4,8]. The main feature that distinguishes agents and ordinary code is autonomy. Agents can cooperate with other agents to carry out more complex tasks than they themselves could handle. One special kind of agent, mobile agent, may move from one system to another to access remote resources or even to meet other agents. Efforts have been made to apply software agent/mobile agent technology in network management as well as in providing QoS guarantees in wired networks.

Portable devices usually roam among places in an unpredictable way and cannot assume any a-priori knowledge about the locally available infrastructure component, resources and services. They should be able to either bind to unknown resources/services in the current locality or to maintain remote connections with resources/services in previously visited places, transparently to the user. Middleware for portable device integration should permit both to discover automatically resources at runtime and to support easy access and utilization of highly heterogeneous components. Middleware solutions should dynamically tailor service provisioning to the specific characteristics of the client access device, which usually exhibits a high heterogeneity of hardware/software capabilities, hosted operating systems, and supported network technologies. Middleware should answer the goal of automating device configuration management as much as possible, to hide

away from final users the wide variety of implementation details of the different heterogeneous devices. Mobile agents will be the underlying enabling technology that we will use in order to develop a powerful middleware that will enhance the fixed networks (and the related Grid services, as described below) and extend the infrastructure services only when and where necessary, without imposing operation suspension. To better identify the different features of the proposed middleware, we will separately examine the different areas present in the reference scenario.

3.1. *Wireless area*

By Wireless Area we mean the coverage area of an Access Point, where one or more mobile devices can be found. Each mobile device (laptop, PDA) has a wireless interface available. This allows the mobile device to communicate and exchange data with the Access Point. Furthermore, the mobile device is characterized by the presence of a fixed agent called Personal Agent (PA). The task of the Personal Agent is to establish a connection between the user and the agents present in the other areas of the scenario. The hardware and software features of the device used must be considered. In particular, the PA will need to know the user's identity and profile, the physical features of the device where it is resident (screen, CPU, and RAM), and the user's actual position, by means of a GPS, for instance. Furthermore it will need to monitor the 'degradable' components of the device (the battery in particular). The PA is automatically created during the boot stage of the device. The initialization of the PA consists of the loading of data corresponding to the user's profile and to the device features. Once the initialization has ended, the PA monitors the network activity, in order to check the input and the output of the WA. When the device enters the Wireless Area, the PA immediately creates a User Agent (UA) in the corresponding Access Point. This User Agent will represent the PA within the Wired Area. The PA will need to be able to locate any User Agents already present in the Wired Area, in order to avoid creating them again. This might happen in the outer areas of the Wireless Area. The consequence might mean entering and exiting the Wireless Area, and might also happen during the user's device changes. In this case, the PA present in the new device should only notify the corresponding User Agent with the new features of the device, which have been read during the initialization. The information exchanged between the PA and the UA concern the data about the device, the user, the state of some device components (battery, wireless card), position, direction, and speed.

3.2. *Access area*

The Access area is the contact area between the Wireless Area and the Wired Area. It consists of the Access Points, which allow the mobile devices to access the services

present in the Wired Area. The task of the Access Points is the management of the issues concerning the user's mobility and his/her movements from a cell to another, by assuring a high level of transparency and continuity of the service. The Access Points need to manage the user's mobility (handoff) and to implement the management policies of the QoS (reservation, allocation and distribution of the bandwidth).

The algorithm used for the management of the QoS in the wireless infrastructure is based on the proactive-reactive hybrid approach described in Section 2. We therefore assume two classes of traffic in the network. The traffic belonging to Class 1 has a higher priority in accessing the bandwidth resources. It represents real-time traffic, while the traffic belonging to Class 2 does not have any strict requests for QoS. The classification in one of the two classes of traffic will be established according to the cost (the service of Class 1 is more expensive than Class 2) and to the type of video requested. For instance, a trailer might belong to Class 2, while a movie might belong to Class 1. Of course, the levels of QoS of class 1 will be higher than class 2. Furthermore, the gap between the higher and the lower level will be much bigger in class 2. This means that class 1 traffic will not experience considerable bandwidth variations, in order to make the audio/video quality acceptable. Conversely, switching from the higher to the lower level of QoS in class 2 traffic might mean a considerable reduction in the quality of the video.

In the architecture described, each Access Point can run an agent platform providing the basic mechanisms for the management of software agents (creation, destruction, and migration). Furthermore, the architecture should allow the communication among the agents, by using an appropriate Agent Communication Language (ACL). The following types of agents will be present in the Access Area: User Agents (UA), GeoLocation Agents (GLA), and QoS Agents (QA). Each time a user enters a cell, a UA is created in the corresponding Access Point. The UA will act as an intermediary for the user within the wired area. As soon as a specific service is requested, the UA starts communicating with the service manager, in order to make it perform the tailoring operations according to the data received from the PA. These operations are the changes needed for adapting the service features as effectively as possible. Then the UA starts the mediation with the QA present in the Access Point, in order to reserve the bandwidth needed for using the service with an adequate QoS. Each time a handoff takes place (that is, each time the mobile device switches from a cell to another), the UA migrates to the new Access Point, and therefore follows the user during his/her movements. In order to know the identity and the address of the new Access Point, the UA sends the data (provided by the PA) about the user's position, direction, and speed to the GeoLocation Agent present in the Access Point. Each GLA knows the position, the addresses, and the identity in detail for all of the Access Points present in the Access Area. Each GLA implements

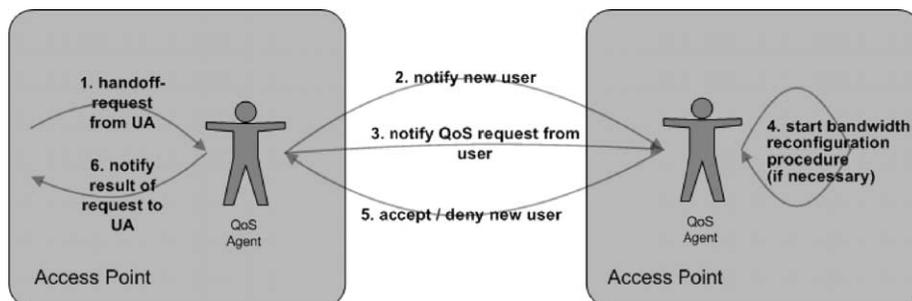


Fig. 1. Interactions of QoS Agents.

the algorithm described in Section 2. Each algorithm enables the GLA to predict the cell the user will move to, according to the direction of movement and the position of the Access Points. Once the cell has been predicted, the GLA sends the identity and the address to the UA for the next Access point that will be visited by the user. Once the UA has received such data, it immediately notifies the QA that the user has moved from a cell to another. This way, the mechanisms of QoS management (bandwidth reservation in the destination cell, and reorganization of the reserved bandwidth in the wired area) are enabled.

Furthermore, the UA can migrate to the new Access Point, by using the data coming from the GLA. If necessary, the migration process of the UA might be divided into two steps, in order to guarantee a continuous service to the user. In this case, the UA should clone itself in the new Access Point immediately before the handoff, in order to notify the service manager with the new position. Then the UA present in the former Access Point should either self-destroy or be destroyed by a Time Out mechanism.

A QA will be present in each Access Point. Its task will be the management of the QoS policies, according to the algorithm described before. Considering the requests coming from the UAs and the QoS policies implemented, the QA performs the bandwidth reservation operations, in order to guarantee each user with the QoS required. The QA exchange some messages, in order to manage the user's mobility effectively. They reserve the resources appropriately, so to 'anticipate' the handoff. Fig. 1 shows the interactions among the QAs.

3.3. Wired area

By Wired Area we mean the fixed network infrastructure that is formed by the Internet in general. Due to the size of the area, no one might think of defining a single strategy for the QoS management. In fact, different policies (IntServ, DiffServ) might be used, depending on the domains visited. In this area we can find the servers that provide the services (MPEG-4 flows) requested by mobile users. Of course, the size of the area also means heterogeneity of the servers it contains. This is a limit for our architecture. In fact, the QoS

management within the Wireless Area cannot disregard the path of the data for reaching the Access Point. This might prejudice the efforts taken to find more effective algorithms for bandwidth reservation, above all with regard to the user's mobility issues. In fact, moving from an Access Point to another might cause a considerable changes in the delays in the Wired Area. This might prejudice the QoS policies established among the Access Points (proactive, reactive, and hybrid approaches).

In order to try to deal with the issue of the coordination of computational and storage activities and resources present in the Wired Area of the architecture, we assume the presence of a Grid computing environment [3,5]. Although still in its infancy, Grid is already successfully used in many scientific applications where huge amounts of data are to be processed and/or stored.¹ We do think that times are mature for the Grid to disclose its potentialities to a wider audience, which is mainly constituted of users with every day problems and requirements. Obviously such needs cannot directly compete with the high demanding scientific applications described so far, but, being the amount of potential users really enormous, the accumulated data processing and storage requirements are at least comparable.

The use of Grid is essential for a transparent and effective management of the computational resources and of the data present in the Wired Area. In fact, the Grid allows to move data, so that it can be made 'closer' to the Access Points where the user is. The tailoring operations will be easier by moving some parts of code. Furthermore, some load balancing operations will be possible by assigning some tasks to the computational resources present in the Grid zone. Even if the architecture described does not depend on the type of service provided, we assume that the user is only interested in using MPEG-4 streams [1]. This assumption allows us to provide more specific implementation details. We therefore assume that the Grid nodes consist of specific MPEG-4 servers that can use the Grid computation

¹ CERN openlab for DataGrid applications. <http://proj-openlab-datagrid-public.web.cern.ch/proj-openlab-datagrid-public/>; SETI@Home. <http://setiathome.ssl.berkeley.edu/>; The DataGrid Project. <http://www.datagrid.cnr.it/>

paradigm, for providing: resource management, information services, security mechanisms, and dial-up services. The main feature of such servers will be the provision of the basic mechanisms for the management of MPEG-4 flows, as well as the opportunity of accessing further state information (Number of users connected, load of the CPU, name of the file requested, duration of the movie requested, current throughput, IP address of the asker, any log about the successful or unsuccessful deliveries requested)

The mobile agent paradigm will be used for managing and coordinating the interaction of the servers, and for providing flexibility in the QoS management. For this purpose, we assume that each node can run an agent platform containing the two following types of agents: Grid Agent (GA) and MPEG Agent (MA). The MA will have the task of monitoring the service requests and the state of the server. The Grid Agent will have the task of managing the Grid services and the movements of data and/or code, the execution of remote jobs, or the access to distributed resources. The MPEG Agents will communicate with the QAs, in order to obtain the data concerning the user's needs for QoS and their mobility. In some cases, MAs might decide to migrate from a node to another, in order to make the communication with other MAs more effective. Conversely, GAs will use the information services provided by the Grid middleware, and will not need the mobility.

The cooperation between MAs and GAs will enable an effective management of the issues related to the network load balancing and to the availability of the resources. Some nodes will be present in the Grid Area, which will make their resources available. However, they will not act as MPEG-4 servers. They will have tasks of data (MPEG-4 files) and code repository, and their computational resources will be used for data transformations (MPEG-4) needed above all during the tailoring operations. As well as the management techniques of the QoS, this will lead to an improved service. From the point of view of the users, this will be seen through the possibility of obtaining more and more information with smaller devices, while being free to move anywhere.

3.4. Interaction mechanisms

For a correct operation of the architecture proposed, a close cooperation among the agents present in the areas of the scenario is necessary, as well as a close interaction with the other hardware/software components belonging to the middleware. As well as cooperating, the agents will also need to interact with the other components of the middleware. For instance, the task of the QAs present in the Access Points will be the interaction with the operating system of the Access Point, in order to enable the management policies of the QoS. In particular, according to the algorithm established, the QAs will be able to reserve the bandwidth, to accept a new user or not, and to allocate the bandwidth according to the requests coming from the UAs.

Two types of agents will be included in the Grid nodes: Grid Agents and MPEG Agents. The former will have the task of interacting with the Grid middleware, by using the available APIs (information discovery through the directory services such as LDAP; remote execution of jobs; movement of data and/or code). Conversely, the latter will have to query the MPEG-4 agent and collect all the information it exports. The following relation has been used for selecting the server where the streaming must be done:

$$Val_{\%}(S_i, A_j) = 100 \times (wl \times (load(S_i)/100) + wu \times (user(S_i)/MAXuser(S_i)) + wthr \times (throughput(S_i)/MAXthroughput(S_i)) + wdst \times (distance(S_i, A_j)/MAXdistance)) \quad (1)$$

where:

$Val_{\%}$ is the percentage value assigned to the i th MPEG-4 server (S_i) at the j th Access Point (A_j);

$load$ is the CPU load of S_i . This value is included between 1 and 100;

$user$ is the current number of users of S_i . This value is normalized through the maximum number of users ($MAXuser$) accepted by the server;

$throughput$ denotes the current throughput of S_i . This is normalized through the maximum possible throughput ($MAXthroughput$) for S_i ;

$distance$ denotes the distance (in terms of latency) between S_i and A_j measured in milliseconds and normalized through the maximum acceptable value ($MAXdistance$);

wl , wu , $wthr$, and $wdst$ are the weights assigned to the parameters load, user, throughput, and distance. Their sum will equal 1.

When the user wishes to access the system for viewing an MPEG-4 video (stored in the Grid zone), he/she runs the PA GUI. After an authentication phase, the PA sends the userID to the Access Point. It is checked that a UA corresponding to this userID is not already active or suspended, and then a new UA is created. If a UA with the same userID already exists, it is required to migrate from the old Access Point, where it is either active or suspended, to the new Access Point. Thus, the UA sends an acknowledge message to the PA running on the mobile device. The mobile device sends the user's request, the information about the user's profile, and the hardware and software features of the client. This stage is necessary, since the user might change his/her access device while moving from an Access Point to another. In general, the user's request consists of a set of keywords representing the video he/she is interested in. According to the information received, the UA requests each MA for the list

of movies that match with the user's preferences, and creates a merge for all the lists received. This list, that indicates also the server where the movie is available, is sent to the PA. At this stage of development, the communications with the MAs are done through broadcast mechanisms managed by the agent platform. This might make the system less scalable. Some solutions are therefore being studied. They are based on peer-to-peer mechanisms, which allow to solve this problem. In order to simplify the video streaming, an rtsp proxy has been installed on each Access Point to hide to the PA the MPEG-4 server. This will help to manage frequent situations of server overload and handoff, which require to change run time the MPEG-4 server used for the video streaming. Thus, the PA will always make reference to the following address: <rtsp://AccesPointAddress:554/SelectedMovie.mp4>.

According to the movie requested, the UA will evaluate if a tailoring of the movie is necessary and eventually recall Grid services for this purpose, and work out the bandwidth needed and notify the QoS Agent present on the Access Point. It will also ask all the servers that are able to process the movie requested, to calculate the $Val_{\%}$ with regard to the Access Point of interest. The server with the lowest ($Val_{\%}$) will be selected. If this does not match with the server containing the movie, the MA will ask the GA to transfer the movie to that server, by using the services made available by the Grid middleware. Once the transfer has ended, the movie is viewed on the wireless device.

If the user roams from a cell to another while using this service, the mechanism described remains valid. In fact, a UA, which performs the actions described so far, is created in the destination Access Point, by using the proactive or reactive approaches described in Section 2. When the user enters the new cell, the new UA prevails on the previous one, and the service continues, even if the server processing the MPEG-4 flow has changed.

4. Implementation and testing

The implementation of the wireless area of the proposed architecture has been initially done with Laptops equipped with Windows 2000 and Linux. Several MPEG-4 Players (Quicktime, RealOne, and MPEG4IP) have been tested on Windows 2000, while the Cisco Open Source MPEG-4 Player has been used in a Linux environment. Then the system has been tested with Compaq iPAQ 3870 Palmtop devices. The operating system Microsoft Pocket PC 2002, InterObject SMIL Player and RealOne player have been used. A version of the PA has been created for each of the operating systems mentioned before. In particular, a JAVA platform has been used for laptops, while a PA, developed for Microsoft Embedded Visual Tools, has been created for Windows Pocket PC.

Fig. 2 shows two prototypes of Access Points, equipped with wireless cards 802.11b. Each AP has been created by



Fig. 2. The MODO Access Points.

using a MODO Mainboard² with an Intel Pentium MMX processor @ 166 Mhz, and 64MB of RAM.

The Access Points used are based on an embedded Linux operating system which occupies less than 16MB on a DOM (Disk ON Module produced by NAGASAKI). The Slakware distribution has been used in the development phase. It has been installed on a 2.5" (10GB) hard disk, in order to make testing and debugging easier. In particular, the use of the command *tc* (traffic control) has become necessary. This command enables to manage the incoming and outgoing traffic from the access points (AP). The traffic is divided into priority queues, or into queues regarding the single flow. The policing, dropping, and metering operation of packets are made on the queues. The software *CellularIP* manages the mobility, and the handoff in cellular systems based on the IP infrastructure. The installation of a DHCP server has become necessary. This server assigns a private Internet address to each new user. The *Iptables* and *Netfilter* packets have been used for creating a firewall, in order to protect the system on the AP, and to create the NAT translation of the addresses assigned.

On each AP a Mobile Agent Platform is executed. We have chosen a minimal version of MAP platform [2] as it is entirely written in Java, offers useful primitives to manage the lifecycle of agents and a complete agent communication language. Finally, a Java Virtual Machine based on Kaffe³ has been necessary, in order to support console applications and the applications of the MAP agent platform.

The Globus Toolkit 2.0⁴ has been selected to implement the Grid environment, and specifically the Resource Management, Information Services, and Data Management services have been used. In order to guarantee an adequate security in accessing distributed resources, the SSL-based security mechanisms have been adopted. The JAVA Commodity Grid Toolkit (JAVA CoG Kit) has been utilized to allow software agents to interact with the Globus environment.

The environment under study is our University Campus. The area of interest is about 10000 m² with buildings, laboratories, classrooms and offices, covered with a 100 Mbit/s fast Ethernet. 8 Access Points MODO have been distributed in order to ensure a good coverage

² MODO. <http://www.tdcitalia.com/modo/modo.htm>

³ Kaffe vm. <http://www.kaffe.org>

⁴ The Globus Project. <http://www.globus.org>

of the campus, with some redundancy to avoid losses as much as possible. The current location (X , Y , and Z coordinates) of each mobile host was detected every second with a GPS module connected through the serial port. Two rtsp-compliant Darwin Streaming Servers (DSS) have been installed on two simple PCs.

We are currently testing the overall architecture described so far. Hundreds of connections are being emulated to stress the DSS, while five mobile users roam inside the campus. We are testing all the basic mechanisms and verifying the hybrid approach for QoS management. Mobile agents are demonstrating their flexibility in dealing with rapidly changing network conditions. The adoption of the Grid paradigm is also extremely useful in ensuring load balancing and optimizing the use of computing and storage resources.

5. Conclusions and future development

During the last few years, wireless technology has become mature enough to satisfy the users' needs for mobility and information anywhere and at any time. In order to manage the challenging problems related to the management of such new environments, in this paper we have defined and partially implemented a reference architecture for effective QoS management, which allows mobile users to access multimedia services (in our case, an Mpeg4 flow), notwithstanding the device used and the user's moves. In order to achieve this purpose with an adequate level of transparency, and considering the heterogeneity of the devices and of the networks, mobile agents have been assumed as the underlying technology, thus exploiting their interesting features of mobility, asynchronicity and autonomy. To effectively manage computing and storage resources available in the wired part of the architecture, the Grid paradigm has been used. Thus, while roaming from a cell to another, a mobile user is constantly connected to the most convenient resource, which is dynamically identified in order to guarantee adequate levels of QoS. The middleware described is currently being tested in an experimental environment, developed at the Engineering Faculty of the University of Messina under the Campus One project, which aims to guarantee Faculty members and students wireless access to multimedia data, while roaming inside the whole University Campus.

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