Control of Multi-User Services in Mobile Heterogeneous Environments

Eduardo Cerqueira, Augusto Neto, Luis Veloso, Edmundo Monteiro
Department of Informatics Engineering of the University of Coimbra
{ecoelho, augusto, lmveloso, edmundo}@dei.uc.pt
Paulo Mendes
DoCoMo Euro-Labs
{mendes@docomolab-euro.com}

Abstract

Nowadays the Internet provides a wide variety of multi-user communication services over heterogeneous environments, where services are destined for large audiences, independently of the location of users and of the moment when those services are requested. Having this in mind, this paper proposes a *QoS Architecture for Multimedia Mobile Multi-user (Q3M)* support, to allow mobile operators to control the dissemination of content to large groups of heterogeneous mobile users, independently of the location of the mobile devices. The proposed architecture is structured in three control functions: the Mobile Multi-user control function that provides the required multicast and unicast connectivity, the Service Class control function that dynamically allocates resources of network classes to multicast traffic, and the Session Management control function that manages the dissemination of content to multiple users. Our conceptual analysis reveals that the Q3M architecture provides the key components for the support of multi-user services over heterogeneous mobile environments.

Key Words: Heterogeneous Networks, Quality of Service, Mobility, Multi-users.

1. Introduction

The emergence of broadband access technologies, such as the Worldwide Interoperability for Microwave Access (WiMAX), and the Digital Subscriber Line and it's variants (xDSL) [1], together with distribution techniques such as the Internet Protocol (IP) multicast [2], allows the implementation of multi-user services in which information is disseminated to large audiences of mobile users. Examples of multi-user services are television, radio, remote learning, software distribution and many other applications such as entertainment and business presentations.

One the other hand, mobile providers need to enlarge their portfolio with the inclusion of dissemination services in order to attract and keep customers, and to combat the triple-play (voice, video and Internet) threat coming not only from traditional video providers, such as cable and satellite operators, but also from copper wire telecom operators. The International Telecommunication Union (ITU) has approved specifications [3] that allow the latter ones to compete cost-effectively with cable and satellite operators to provide triple play services, namely multiple high-quality digital video streams, high-speed Internet access and voice services.

Hence, mobile communications are at the edge of another metamorphose. On the one hand we have voice services on top of cellular circuit-switched systems, and on the other hand we have Internet services on top of a packet-based system. Most of the operators face today the challenge of integrating any type of communication services on top of an IP based packet-switched network, whose multiplexing capability is able to reduce operation costs. Until now, mobile operators have showed potential to lead the evolution of mobile communications, by providing Internet services to their customers via the combination of voice-circuit-switch services and Internet-packet-switch services. The next step, at the network level, will lead to the integration of multi-user services, which may have different Quality of Service (QoS) requirements, in a packet-switch heterogeneous network. In order to keep a leading position, mobile operators must rely on a service-centric architecture, in which the customer is the reason of existence of any service.

Some research efforts have been performed to build QoS architectures in mobile heterogeneous environments. Among them, the Mobility and Differentiated Services in a Future IP Network (Mobydick) project [4] proposes an architecture for heterogeneous networks that involves aspects of mobility, fast handover, QoS and charging. The Mobility and Service Adaptation (MASA) QoS architecture [5] proposes an end-to-end framework, which supports QoS for mobile scenarios in a heterogeneous network environment. However, both proposals are focused in one-to-one or one-to-few services supported by unicast environments, use QoS Brokers for controlling a QoS domain, thus reducing the system scalability, and do not provide mobility estimation and prediction in order to achieve seamless handover and to anticipate the reservation of network resources.

To overcome the above mentioned limitations concerning the support of multi-user services, and in order to enable the dissemination of multimedia and data-content to large audiences in future packet-switched networks, we propose an architecture called *QoS Architecture for Multimedia Mobile Multi-user (Q3M)*. The Q3M architecture allows mobile providers to differentiate their network services not only by offering bandwidth-centric networking, but rather by offering service-centric self-organized networking. The latter model provides many benefits, such as customization, ease control with few human interventions, and usability in heterogeneous mobile environments.

The remainder of the paper has the following organization. Section 2 analyses the applicability scenario of the Q3M architecture. Section 3 presents the Q3M architecture and its main components. Section 4 discusses the advantages of the Q3M architecture for the proposed scenarios. Finally, Section 5 presents some conclusions and directions for ongoing and future work.

2. Applicability Scenario of the Q3M Architecture

The Q3M architecture aims to provide self-organized multi-user communications in a heterogeneous mobile environment. This section describes the services targeted by the Q3M architecture, and the assumed network infrastructure and mobility conditions.

2.1. Services

The Q3M architecture assumes that multi-user communication services include one sender and N receivers. Multi-user services are not limited to broadcast applications such as television and radio, and these are far from representing the complete range of multi-user applications, which can also include [6]:

- Scheduled audio and video distribution, which can also support remote lectures, business presentations, meetings, on-line concerts;
- Push media for news headlines, weather updates, news health, sport scores and other types of non-essential dynamic information;
- File distribution and caching for spreading web site content, executable binaries, software-updating and other file-based updates sent to distributed end-users or caching on replication sites;
- Announcements for network time information, grid computing data and other types of information that are commonly useful;
- Monitoring information diffusion services to the end-users, which can inform receivers about stock prices, seismic activity and other types of real-time information.

In terms of QoS, the above application groups have distinct requirements. For instance, scheduled video and audio services, which are characterized by long live sessions, have relatively high bandwidth demands and medium end-to-end delay and jitter (delay variation) requirements. In addition, in an audio and video combination, it is more important to ensure an intelligible audio stream than a perfect video.

Short live push media sessions are characterized by relatively low bandwidth data, while file distribution and caching has medium bandwidth. However, both applications present a high tolerance to delays. For announcements, low bandwidth and medium delay is required, while the diffusion of monitoring information has medium bandwidth and low delay.

Besides bandwidth and delay, the tolerance to losses is also an important requirement. On the one hand, video and audio applications are known to have relative loss tolerance. On the other hand, while push media has a high tolerance to losses, file distribution may exhibit low loss tolerance. This happens because while the latter may have the immediate attention of the user, the same does not occur with push media. Table 1 summarizes the quality requirements of the considered one to *N* multi-user dissemination services.

Table 1 - QoS requirements of one to *N* dissemination services

Application Groups	Bandwidth	Loss Tolerance	Delay Tolerance
Scheduled Video and Audio	High	Medium	Medium
Push Media	Low	High	High
File Distribution and caching	Medium	Low	Low
Announcements	Low	Medium	Medium
Monitoring information diffusion	Medium	Low	Low

The proposed Q3M architecture allows mobile operators to support the enumerated multi-user applications, while expanding to other markets, such as education, remote business, health-care, and distribution services like advertisement.

2.2. Network Infrastructure

Next generation networks are envisioned to have an IP backbone combined with optical technologies interconnecting many IP wireless access networks, providing ubiquitous access to customers through a vast variety of wireless devices. In this context, the research community is targeting towards the development of networks that rely on IP for packet transferring and exploit IP based protocols to perform fundamental operations, like mobility, seamless QoS, and multi-user communications.

In what concerns QoS, there have been a considerable number of research efforts, all of which did not have the expected impact. Basically, the reason for failure is the pace at which networking technologies have evolved. That is, by the time QoS mechanisms are ready to be deployed they lack technological relevance. As mentioned by Jon Crowcroft et al. [7], and illustrated in Fig. 1, the ratio of core and access bandwidth has changed over time. In that Figure, peaks are periods of plenty core bandwidth and low amplitudes correspond to periods where the core bandwidth is matched or exceeded by access bandwidth. In addition to the access technologies illustrated in Fig. 1, we can mention also broadband mobile access technologies, such as Wireless Local Area Network (WLAN). The conclusion is that research on network resources control must be forward-looking, both in relation to the services to which it will be applied to, and in relation to its realization, which should occur when solutions to control network resources are less needed. Moreover, we must not forget that QoS should mean not only the support of application performance, but also the mechanisms required to differentiate the quality levels delivered to different traffic classes, which may be needed for any core to access bandwidth ratio.

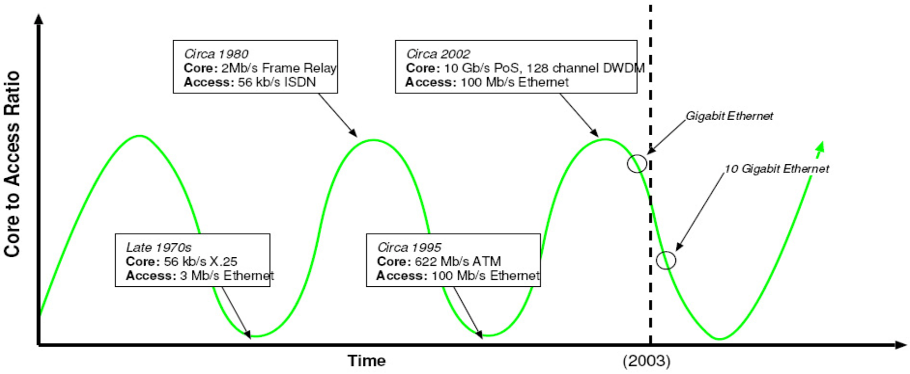

Figure 1 - Relative core to access bandwidth ratio over time [7]

Taking such research strategy into account, the Q3M architecture aims to support session dissemination to mobile users, while differentiating traffic in distinct quality classes. The proposed Q3M architecture targets a next generation of heterogeneous IP based networks, as shown in Fig. 2. In this scenario access networks will provide connectivity to geographically co-located mobile devices based on different technologies, such as WLAN based on the 802.11 standard, Wireless Metropolitan Area Networks (WMAN) based on the 802.16 standard, and Wireless Wide Area Networks (WWAN) based on the third and fourth generation cellular networks. Moreover, these access networks can be fixed or mobile.

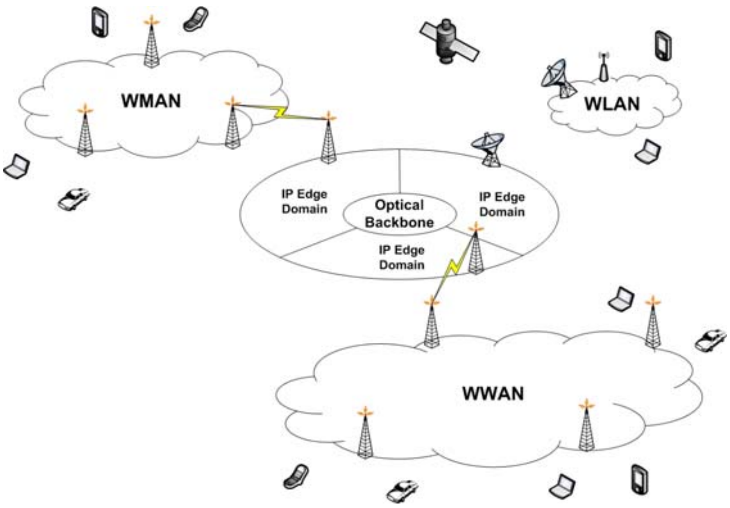

Figure 2 - Heterogeneous IP network infrastructure

As shown in Fig. 2, it is assumed that mobile operators may rely on optical technology in the core backbone for high-speed communication, while keeping IP technologies at the edges to provide a set of different services to their customers.

Service differentiation into network classes is also assumed in access networks such as third and fourth generation cellular networks, 802.16, and 802.11 (based on priorities). Each service class defines a specific combination of bounds on performance metrics and offers a specific traffic forwarding behaviour. Class-based provisioning architectures avoid the scalability and complexity problems of provisioning models based on flows, since service classes are provided based on traffic aggregates rather than on a per-flow basis.

Multi-user applications may involve large audiences. Therefore, IP multicast is more suitable to support dissemination services than IP unicast, since it allows a single data stream to be sent simultaneously to multiple devices, leading to savings in network resources, especially in backbone networks. Hence, it is assumed that mobile operators will deploy IP multicast in their backbone network in order to save network resources while the number of customers increase. However, the same assumption cannot be made to all networks, namely for some access networks, which may have a small number of customers. This means that the Q3M architecture provides multi-user communications in a scenario where the range of IP multicast services is assumed to be edge-to-edge and not end-to-end.

2.3. Mobility

The dramatic increase in the number of wireless and mobile devices coupled with the desire to connect them to the ever-growing Internet is leading to a mobile Internet, where support for the mobility of devices will soon be taken for granted.

The mobility of IP-based devices leads to the change of routes usually at the edges of networks, due to the attachment of mobile devices to different access routers. The irregular traffic pattern induced by this behaviour leads to an increasing difficulty to control the traffic entering and leaving a network. This is, the difficulty to predict were resources will be needed makes the provisioning of networks a harsh task. The impact of this irregular traffic pattern increases in the presence of moving networks, since these networks encompass a high number of devices that provokes a drastic change in the traffic pattern observed in the core network.

In the special case of multimedia applications some of the traffic is long-lived, which makes its control somehow simplified. However, in a mobile environment this advantage disappears, because, although streams are still long-lived at the application level, they are short-lived in all used network paths leading to a higher number of control operations.

Mobility also involves the change of IP addresses of mobile devices. Since IP addresses are usually part of flow identifiers, the change of the former implies the change of the latter. This impacts the way resources are allocated in a network, since the allocation of resources to flows is managed based on their identifiers.

The effect that mobility has in the control of resources allocated to flows goes beyond the hassle provoked by the change of IP addresses. More precisely, the mobility of a flow between two access routers is different from having one flow ending in one edge of the network and a different one starting at a different edge. The justification is that in the case of a moving flow, resources must be settled in the new path fast enough to avoid the degradation of the service provided to the mobile user. Moreover, the total disruption of the service can occur if resources cannot be settled at all in the new path.

3. The Q3M Architecture

This section describes the baselines of the Q3M architecture to support multi-user services characterized in section 2.1 on a next-generation network infrastructure described in section 2.2, and considering the mobility implications briefly presented in section 2.3. The proposed architecture provides three types of control functionalities: the Mobile Multi-user Control Function (MMCF), the Service Class Control Function (SCCF) and the Session Management Control Function (SMCF). Fig. 3 introduces a general scenario showing the location of the Q3M control functions.

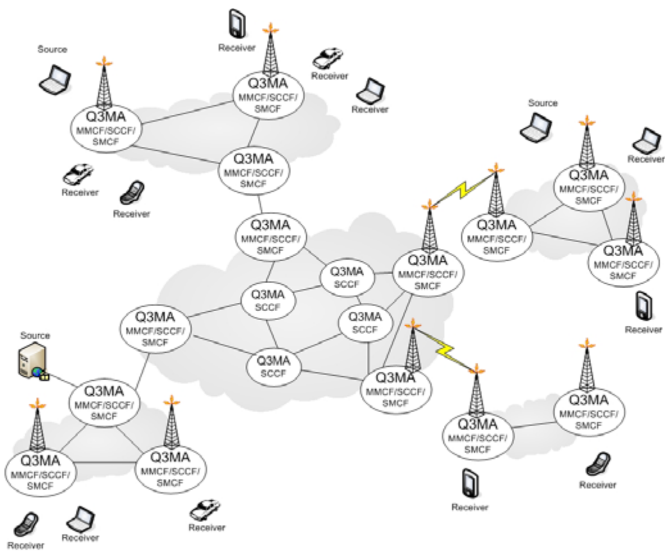

Figure 3 – Location of the Q3M control functions in a general scenario

The three control functions are integrated in an element, called Q3M Agent (Q3MA) that is located at the edges of each network. Nevertheless, the presence of all control functions is not mandatory in all Q3MA. For instance, in Fig. 3 only the backbone network is class-based, which means that the service class control function is only active in the Q3MAs of that network. Although not all access networks are IP multicast-aware, the mobile multi-user control function is present in all of them, since this function controls the movement of devices, independently of their connectivity capability (multicast or unicast). The session management control function is present in all Q3M-aware networks, since it controls all multi-user communication sessions, independently of the position of the involved devices.

Fig. 4 shows the integration of the Q3MA control functions in a protocol stack represented by its data and control planes. The structure of the data plane follows the standard TCP/IP architecture with the Differentiated Service model (DiffServ) modules [8] and the Mobile IP (MIP) components [9]. The control plane integrates signalling protocols to support multicast communications, through the Protocol Independent Multicast - Source Specific Multicast (PIM-SSM) [10], the Session Initiation Protocol (SIP) [11], the Session Description Protocol (SDP) [12] and the Session Announcement Protocol (SAP) [13]. At link layer, the control plane encompasses mobile technologies, such as UMTS [14]. Q3MAs also use cross-layering mechanisms for a tighter communication between the different control layers in order to increase their functionality.

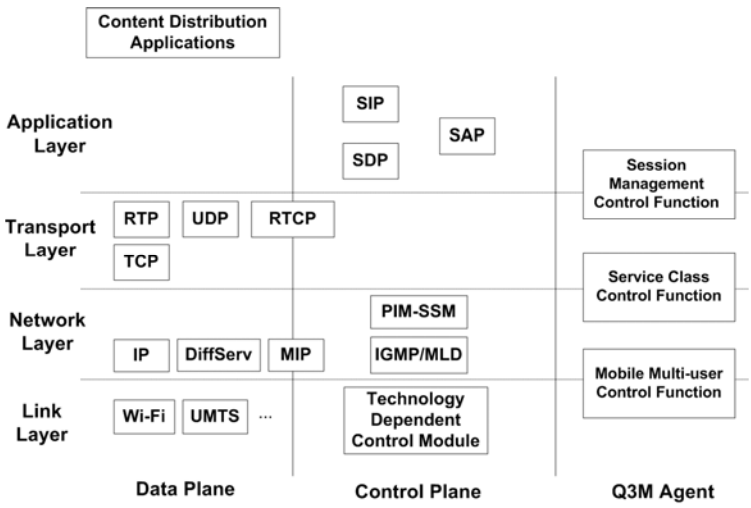

Figure 4 - Q3MA: control functions integrated in the TCP/IP protocol stack

Although it is proposed to deploy Q3MAs at edge nodes, it may be possible to see Q3MAs in interior network nodes for QoS purposes, such as resource reservation. Nevertheless, this extension manages network resources only in a per-class basis, requiring reduced state in core nodes.

3.1. Mobile Multi-user Control Function

The Mobile Multi-user Control Function (MMCF) enables seamless multi-user mobile communications over heterogeneous access networks, such as IP unicast and IP multicast networks, as well as networks that use other multicast approaches, such as UMTS networks. For instance, this functionality provides operators with the capability to control the mobility of devices between multicast and unicast networks, including address translation and multicast reflection.

The MMCF is divided into three main sub-modules [15]: the Connectivity Control sub-module that is responsible for the connectivity of mobile nodes in different access networks, the Handover Management sub-module that determines the actions to take when the mobile node accomplishes an handover, and the Mobility Prediction sub-module that is responsible for predicting the most probable cells to where the mobile node will move.

Therefore, the MMCF allows clients to use multi-user communications anywhere and anytime, which means that the control of multicast trees has to reflect the movement of senders, receivers and networks. While IP multicast brings benefits to receivers' mobility, due to the meaningfulness of multicast addresses in different networks, application-layer multicast may help to manage the mobility of senders.

Moreover, the MMCF provides the capability to build multicast trees in scenarios where the QoS characteristics of the available paths may be strongly asymmetric and fluctuate rapidly. Special attention is given to situations where some paths may be available only time-to-time due to fluctuating radio connections or mobility. Hence, the MMCF is able to build multicast trees in straight collaboration with the service class control function, and with unicast constraint routing protocols when they are available. The MMCF does not require any modification to standard IP multicast protocols, operating in a self-organized manner, and allowing an incremental deployment.

In addition, in order to achieve seamless handovers between heterogeneous networks, the MMCF is responsible for predicting the location of mobile users. This is, the localization of the most probable cells to where the mobile node will move. This information will be used in mobility management and for anticipating the reservation of network resources.

3.2. Service Class Control Function

The Service Class Control Function (SCCF) provides the capacity to manage service classes, allowing network operators to define a set of different services with different quality levels and different costs. For instance, different network services may be built for scheduled audio and video distribution, and for push media services, due to their different QoS requirements.

The SCCF is divided into four main sub-modules [16]: the Multicast Resource Reservation Protocol sub-module that is responsible for signaling and state manipulation mechanisms at all nodes within the network, the Resource Monitoring Protocol sub-module that is responsible for per-class measurements to get information about the usage of network resources, in order to support self-adjustment of resources and to support admission control decisions. This understanding of the network behaviour, namely considering the dynamic traffic pattern of mobile flows due to handovers, can leverage the efficiency of the network with the capability to predict events. Besides these two protocols, the SCCF module encompasses an Admission Control sub-module that decides whether a session may be admitted, taking into account the required amount of resource and its availability in the data path, and an Over Reservation Control sub-module that manages the extra amount of bandwidth to be reserved, and which can be based on mobility and traffic patterns

Thus, all decisions about the dynamic provision of network service classes are made at the edges of networks, being interior nodes only responsible to adjust the resources allocated to each class. Focusing the computational effort at the edges makes the network scalable with the number of customers and their mobility.

In addition, SCCF is able to optionally create multicast trees at the same time that resources are being reserved in each node along the data path. Moreover, the interaction with the Multicast Routing Information Base (MRIB message) is also combined with the above action, in order to force that all posterior PIM-SSM join messages to follow the same downstream data path, avoiding possible problems caused in environments with asymmetric routing.

3.3. Session Management Control Function

The Session Management Control Function (SMCF) is essential to control all multi-user sessions in the Q3M architecture in a self-organized manner, independently of the location and technology of the involved devices. With this goal in mind, the SMCF is divided into three main sub-modules responsible by specific functions and services [17]: The Announcement Control sub-module that is responsible for controlling the distribution of session advertisements, the Access Control sub-module that is responsible for controlling the access of heterogeneous users to the available services, and the Dissemination Control sub-module that is responsible for supporting session dissemination as a way to assure the quality level of the services requested by end-users.

Heterogeneous mobile end-users will need, due to the abundance of content, a session announcement mechanism that will help them to receive announcement content, independently of the available technology (unicast or multicast) and independent of their location. With this goal in mind, the Announcement Control is responsible for the creation/updating of a decentralized database with information about all ongoing multi-user sessions in all Q3M networks. The Announcement Control function is configured based on policies that support content dissemination based on previous inter-network agreements. Such scheme, allows Q3MAs to spread session content to Q3MAs belonging to the same network and between different networks. Moreover, based on the Hyper Text Transfer Protocol (HTTP), receivers can know about the available sessions by transparently querying the closest Q3MA.

The Access Control function is an end-to-edge approach that makes use of the SIP protocol to allow users to subscribe to previously announced dissemination channels, and of SDP to describe users' sessions. The use of SIP and SDP to control access to dissemination channels makes the Q3M architecture compatible with other technologies, like for instance third generation networks.

Finally, the Dissemination Control function provides a solution to transport, identify and map the quality level of multi-user services requested by heterogeneous mobile users. It matches the suitable association between the users' session requirements with the classes of services supported by each network along the session path. Thus, based on the session requirements and on the available network resources, it defines which class will be mapped for a session at the edges of networks. Moreover, it adapts sessions to the current network conditions, for instance, by dropping low priority dissemination channels. The implementation of the adaptation mechanism in edge devices is a suitable solution for mobile environments, in which wireless links are narrow-band.

4. Advantages of the Q3M Architecture

Currently we are involved in the implementation of the three control functions, which will be validated in an experimental test-bed and in a simulator. Therefore, this section describes a first evaluation analysis of further advantages of using the Q3M architecture to cope with the requirements of multi-user services.

The first advantage is brought by the Mobile Multi-user control function that makes the Q3M architecture suitable to be used independently from the routing capabilities of each network, allowing the use of multi-user applications anywhere. For instance, although IP multicast is the default choice to support multi-user communications, the Q3M architecture still supports multi-user services even if access networks are not multicast capable.

In what concerns the Service Class control function, it allows the control of network services independently from the QoS model used in the data plane. This is useful, since although several attempts are being made to standardize a set of services classes, such as the Integrated Services model (IntServ) [18], the UMTS service definition [19], and the ITU QoS classes [20], each of these frameworks defines a different number of classes. On the other hand, the DiffServ model, does not delineate a specific set of service classes, but only provides a rough outline of how services can be defined. The DiffServ model brings more flexibility to develop network services, since it does not propose rigid network service formats, but only what must be their operational boundaries. This seems more suitable for a scenario where operators would like to provide services to audiences with changing communication requirements, while optimizing the usage of network resources. However, the DiffServ model does not define a control plane to manage the number of implemented services and to decide where in the network should each service be present and when.

The flexible control of network service classes creates a service-centric networking approach that makes the support of adaptive business models easier. For instance, advanced network services may be enabled on-demand, allowing different network operators to offer a set of different services, which increases competition. That is, the Q3M architecture supplies a flexible mechanism to manage a dynamic set of differentiated service classes, allowing network providers to attract customers and to keep them loyal. This loyalty is substantiated by providing customers with a personalized view of the network services, by assigning different quality expectations to different type of customers.

Finally, the self-organized control of the Q3M architecture supports flexible autonomous networking. This means that the Q3M architecture is able to adapt to new situations, such as the deployment of new network service classes to support different applications. The autonomy of the Q3M architecture is based on the distribution of control among edge Q3MAs. This capacity to self-organize its functionalities allows the Q3M architecture to operate with little configuration effort from the network manager, who is only required to set and update operational policies.

5. Conclusion

This paper proposes a QoS Architecture for Multimedia Mobile Multi-user (Q3M) allowing mobile operators to expand their business, by supporting multi-user services over heterogeneous environments. These services are provided in a broadband ubiquitous environment, since whether customers are static or on the move, they will take seamless access to broadband for granted across any access network.

The Q3M architecture was designed to support the requirements of multi-user services in terms of QoS, cost and ubiquity, including dynamic service provision and admission control mechanisms. The Q3M architecture provides also service availability control, with little human intervention, in three levels. In the first level, the Mobile Multi-user control function provides the required multicast and unicast connectivity. On a second level, the Service Class control function dynamically allocates resources to network service classes, and on a third level, the Session Management control function guarantees and supports the dissemination of content over heterogeneous environments. The integration of these three control levels provides the correct management of the dissemination of content to large groups of mobile users in a self-organized manner.

The Q3M architecture is currently being developed in a joint project between DoCoMo Euro-Labs and the University of Coimbra. The main concepts and components are already defined and the team is now involved in the detailed specification, implementation and validation of the Q3M architecture. Preliminary analysis reveals that the architecture is able to cope with the requirements of emerging dissemination services for mobile users.

References

[1] A. Ghosh, D. Wolter, J. Andrews, R. Chen. "*Broadband wireless access with WiMax/802.16: current performance benchmarks and future potential*". Communications Magazine, IEEE. vol. 43, pp. 129 – 136, Feb. 2005.

[2] S. Deering. "*Host Extensions for IP Multicast*". RFC 1112, Internet Engineering Task Force, August 1998.

[3] ITU-T Study Group 16. "*Full Service VDSL Systems Architecture*". Technical Report, ITU-T, June 2002.

[4] V. Marques, R. Aguiar, P. Pacyna, N. Chaher, C. Garcia, J. Moreno, H. Einsiedler. "*An architecture supporting end-to-end QoS with user mobility for systems beyond 3rd generation*". IST Mobile & Wireless Telecommunications Summit, Greece 2002.

[5] C. Niedermeier, C. Fan, D. Carlson, A. Schrader. " *MASA – A Scalable QoS Architecture*". 7th IASTED International Conference on Internet and Multimedia Systems and Applications, Hawaii, August 2003.

[6] B. Quinn, K. Almeroth. "*IP Multicast Applications: Challenges and Solutions*". RFC 3170, Internet Engineering Task Force, September 2001.

[7] J. Crowcroft, S. Hand, R. Mortier, T. Roscoe, and A. Warfield . "*QoS's downfall: at the bottom, or not at all!*". In Proc. of ACM SIGCOMM, Germany, August 2003.

[8] S. Blake, D. Black, M. Carlson, E. Davies, Z. Wang, and W. Weiss. "*An Architecture for Differentiated Service*". RFC 2475, Internet Engineering Task Force, December 1998.

[9] I. Akyildiz, J. Xie, S. Mohanty. "*A Survey of Mobility Management in Next-Generation All-IP-Based Wireless Systems*". IEEE Wireless Communications, August 2004.

[10] S. Bhattacharyya. "*An Overview of Source-Specific Multicast (SSM)*". RFC 3569, Internet Engineering Task Force, July 2003.

[11] J. Rosenberg, H. Schulzrinne, G. Camarillo, A. Johnston, J. Peterson, R. Sparks; M. Handley, E. Schooler. "*SIP: Session Initiation Protocol*". RFC 3261, Internet Engineering Task Force, June 2002.

[12] M. Handley, V. Jacobson, C. Perkins. "*SDP: Session Description Protocol*". Internet Draft, Internet Engineering Task Force, February 2005.

[13] M. Handley, C. Perkins, E. Whelan. "*SAP: Session Announcement Protocol*". RFC 2974, Internet Engineering Task Force, October 2000.

[14] 3GPP TR 23.846 6.1.0. "*Multimedia Broadcast/Multicast Service (MBMS): Architecture and functional description*". Technical Report, 3GPP, December 2002.
[15] L. Veloso, P. Mendes, E. Monteiro. "*Mobility Management for Mobile Multi-User*". Technical Report, D-2-2-A, February 2005.
[16] A. Neto, P. Mendes, E. Monteiro. "*Service-centric Control for Mobile Multi-user*". Technical Report, D-3-2-A, February 2005.
[17] E. Cerqueira, P. Mendes, E. Monteiro. "*Session Management for Mobile Multi-users in Q3M Architecture*". Technical Report, D-4-2-A, February 2005.
[18] P. White. "*RSVP and Integrated Services in the Internet: A Tutorial*". IEEE Communication Magazine, vol. 35, pp. 100-106, May 1997.
[19] G. TS23.207. "*End-to-end Quality of Service Concept and Architecture*". Technical Report, 3GPP, June 2003.
[20] N. Seitz. "*ITU-T QoS Standards for IP-based Networks*". IEEE Communication Magazine, vol. 41, pp. 82-89, June 2003.