A Feasible Approach for QoS Management in Coordinated Heterogeneous Radio Access Networks

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Abstract

This paper develops a feasible architecture for end-to-end QoS management over B3G networks where multiple heterogeneous radio access networks (RAN) can be coordinated at radio level by means of supporting Common Radio Resource Management (CRRM) functionalities. The presented approach is claimed to be innovative as long as it is inspired in the most relevant trends being developed in different fields and forums and come up with a global solution capturing such partial concepts. A key point of the architecture is the introduction of a Wireless QoS Broker entity that becomes the link between CRRM and E2E QoS management. In the paper, after introducing the proposed QoS framework, the signaling and procedures to support such architecture in the B3G network are addressed. Over such a basis, a connection establishment procedure is discussed to show how the problem of initial RAN selection can be managed by the proposed architecture.

1. Introduction

It is generally acknowledged today that the Beyond 3G network concept encompasses network heterogeneity. A plethora of different radio access networks (e.g. cellular networks as GPRS and UMTS as well as WLAN hotspots) will have to co-exist. These different networks ought to be inter-connected in an optimum manner with the ultimate objective to provide the end-user with the requested services and corresponding QoS (Quality of Service) requirements. In a heterogeneous radio access network (RAN) scenario wireless users can be given access to their services through different available radio access technologies (RAT). A key issue in such complex scenarios where different degrees of interworking may exist (e.g. tight and loose coupling architectures for WLAN and UMTS integration) as well as different usage strategies (e.g. introduction of economical costs criteria) is how QoS can be managed and provisioned in a flexible and affordable way over the whole set of available RATs. Besides, QoS provisioning in the different RATs can be based on different technology-specific mechanisms, thus making even more challenging the need to harmonize them in order to fulfill the B3G network concept.

The envisaged beyond 3G scenarios introduces a new dimension into the radio resource management problem, in addition to the need for a proper interworking among RATs through adequate architectures. That is, instead of performing the management of the radio resources independently for each RAT, some form of overall and global management of the pool of radio resources can be envisaged. Common Radio Resource Management (CRRM) is the envisaged process to manage dynamically the allocation and de-allocation of radio resources (e.g. time slots, codes, frequency carriers, etc.) within a single or between different radio access systems for the fixed spectrum bands allocated to each of these systems. In this way, a more efficient usage of the available radio resources can be achieved. 3GPP coped for the UTRAN/GERAN CRRM issue with main contributions in Release 5 [TR 25.881, TR 25.891], though in Release 6 several options were considered but any new functionality has been added yet. In any case, CRRM functionalities should be incorporated someway into the end-to-end QoS management framework in order to encompass critical decision processes such as RAT selection for served connections.

Another promising approach to be considered in a B3G QoS management framework is Policy-Based Networking (PBN). PBN is a novel technology that facilitates the management and operation of networks. In today’s highly competitive market, policy-enabled networks appear as a promising approach to reduce the cost of network operation and maintenance while providing a great flexibility to satisfy the demands of complex service provision frameworks. Policy-based management allows operators and networks providers to deploy and correlate business strategies with the overall network actions. Cellular networks are not unaware of this potential and some important efforts have been already overtaken to introduce service policy-based QoS control in the IP

Multimedia Subsystem (IMS) of the 3rd generation UMTS networks [1]. The Policy Decision Function (PDF), which is currently being standardized in the 3GPP as part of the UMTS IMS, exploits policy-based technology for provisioning of IP QoS services. However, the IMS approach is mainly targeted to IP resource authorization within an UMTS domain and it is completely unaware of the radio access part. Policy-based QoS management frameworks have already been proposed for integrated scenarios such as UMTS and WLAN [2]. But again, the scope of the proposed framework in this work [2] is limited, as in the IMS framework, to handle IP resources for QoS provisioning in each domain and assure the consistency of the policies applied in each one.

This paper discusses the introduction of policy-based mechanisms for QoS control in the Beyond 3G (B3G) network paradigms built around the UMTS architecture and the integration of heterogeneous radio access networks with CRRM functionalities. The conducting line of the paper is the identification of the involved entities and their mutual interactions for enabling end-to-end policy-based QoS over a B3G system. Therefore, the proposed policy-framework encompasses IP resource management in the CN as well as the common radio resource management of the access part. The proposed QoS framework is being developed within the IST EVEREST project [3] targeted to the study of advanced radio resource management over integrated heterogeneous radio access networks.

The paper is organized as follows. In Section 2 a general overview of the problematic of the end-to-end QoS management in a beyond 3G scenario is provided. Next, in Section 3, the main aspects of the current 3GPP QoS framework are analyzed as they serve as the basis for the definition of the proposed end-to-end QoS management presented in Section 4. Then, the signaling needs and the required functionalities in the proposed architecture are discussed in Section 5 and a connection establishment procedure is detailed as an example. Finally, some conclusions close the paper in Section 6.

2. E2E QoS in B3G network scenarios

The considered reference architecture for the B3G network consists of a set of heterogeneous radio access networks (UTRAN, GERAN and WLAN) interfacing a common core network (UMTS CN). Each Radio Access Network is built around a specific radio access technology and an extended UMTS core network is used to interconnect all the RANs. In the release 5 of UMTS the CN is an IP based network. SGSNs are connected to RNCs through the Iu-PS interface where ATM is used at layer 2 and IP can be used at layer 3. In the IP CN of UMTS, one can consider that no specific QoS provisioning mechanism below the GPRS Tunneling Protocol (GTP) is needed if the IP CN itself and the Internet backbone are not considered bottlenecks of the system. However in a heterogeneous access network where the IP CN has to support several types of radio access technology and has to deliver different network services to users, a QoS mechanism will be needed in order to fulfill these requirements and to use efficiently the CN resources (over-provisioning would not be cost-effective). In the CN QoS mechanisms at the transmission medium (ATM or another technology) could be used. The IP QoS mechanism envisaged here is based on the DiffServ framework [4].

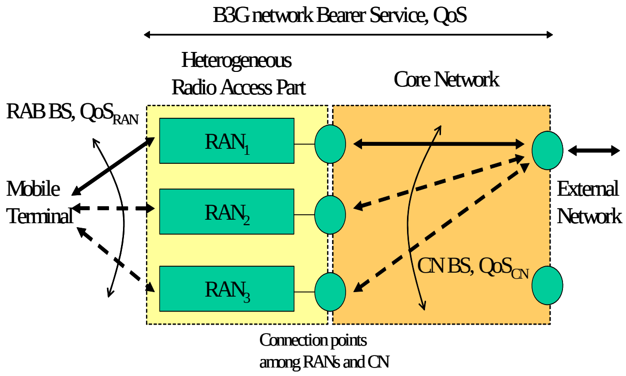

Figure 1. Basic problematic of QoS provisioning over a B3G network.

Within this B3GN concept, services should be delivered via the most suited RAN. A basic approach of the problematic of QoS management over a B3G network is illustrated in Figure 1. Each RAN will provide the user connectivity to the CN through specific attachment points. Then the CN will be in charge of handling the connectivity between the RAN attachment points and the gateway(s) through which the access network is connected to external IP networks. Thus, QoS management within the overall network should provide a decision on which RAN is the most appropriate to handle a particular connection and how QoS requirements are balanced among the access part and the core network. Answers to these questions really go beyond a "simple" solution focused on resource optimization and lead to complex scenarios where decisions can be taken according to many other criteria such as terminal capabilities, radio access network capabilities, user preferences and network operator preferences.

3. Current 3GPP QoS Framework

A policy-based framework is introduced in 3GPP release 5 to manage QoS for multimedia services supported within the IMS Domain and the framework is extended to other services in release 6. This policy framework is intended to enable the coordination between events at the application/service layer and resource management at the IP bearer layer and it can be used to provide a policy-based admission control in charge of authorizing specific QoS resources for a set of IP flows within a user session. In this way, the service provider (e.g. the mobile operator) could decide which level of IP QoS is offered taking into consideration the characteristics of the service being requested but also any other consideration related to business models and management (premium users, etc.). This 3GPP UMTS policy framework [1] is aligned with the policy framework defined within IETF. According to this IETF framework, the UMTS framework introduces the Policy Decision Function (PDF) entity, which is equivalent to the PDP in the IETF model, and the Policy Enforcement Point (PEP), located in this case in the GGSN. Additionally, the policy-based framework in release 6 considers the existence of a logical element referred to as Application Function (AF) which is really in charge of offering services that require the control of IP bearer resources. The AF entity for IMS services (based on Session Initiation Protocol, SIP) is the SIP proxy referred to as P-CSCF (Proxy Call Session Control Function) in 3GPP terminology. In release 5 the PDF is collocated with the AF. A simplified view of this policy framework is illustrated in Figure 2. G_q interface between AF and PDF is being currently defined as a Diameter protocol extension whereas G_o interface between PDF and GGSN is based on COPS [5] .

Within the 3GPP IMS, session establishment and modification involves an end-to-end message exchange using SIP/SDP with negotiation of media attributes (e.g. codecs). If the IMS applies Service Based Local Policy (SBLP) then the AF (SIP Proxy) accesses to the SIP message, in particular to the SDP body, and forward the relevant SDP information to the PDF via the G_q interface together with an indication of the originator. The PDF notes and authorizes the IP flows of the chosen media components by mapping from SDP parameters to authorized IP QoS parameters for transfer to the GGSN via the Go interface. After an authorized session, the UE receives the SIP/SDP message jointly with an authorization token. Then, the UE performs its own mapping from the SDP parameters and application demands to some UMTS QoS Parameters in order to populate the requested QoS field within the PDP (Packet Data Protocol) context activation or modification. The authorization token is also included in the PDP Context request activation. The GGSN receives this token and sends it to the PDF in a COPS REQ message. The PDF responds with a COPS DEC message with contains the authorized IP QoS characteristics as well as the packet flows that can use the PDP context. The GGSN then maps the authorized IP QoS parameters to the authorized UMTS QoS parameters and if the PDP context request lies within the limits authorized by the PDF, the PDP context activation or modification shall be accepted. A good overview of the 3GPP policy-based framework is given in [6].

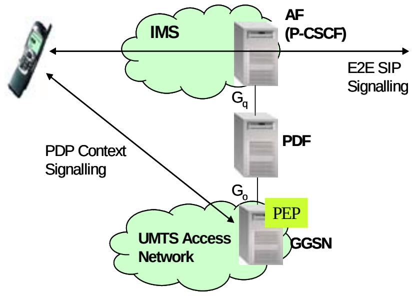

Figure 2. **3GPP policy-based QoS framework**

4. Proposed QoS framework

A QoS management architecture extending the 3GPP policy-based framework is proposed hereafter to address the QoS problematic within B3G networks. The 3GPP policy-based framework for IMS services can be seen as the first step to introduce policy-based technologies in wireless networks but several extensions would be required to fulfill B3G QoS requirements:

- In the current 3GPP QoS framework, authorization of a session in the PDF is done without taking into account radio network resources. This could lead to situations in which a session is authorized at the PDF but then the admission control mechanism triggered by the PDP Context activation may reject the establishment of resources for that request. Although in a single access network scenario such as UMTS this situation does not have too much relevance, in a scenario where several access network options co-exist this situation could lead to block a session authorized over a specific RAT (e.g. selected based on operator preferences) while enough resources are available in another one.
- Allow end-to-end resource-based admission control. From the same reasons stated in previous paragraph, the PDF would authorize sessions despite resource limitations or congestion in the external network(s).
- The policy-based framework should be extended to cope with resource management in the radio access part as well as in the CN. In this sense, resource usage in the entire B3G network elements is expected to operate under a set of policies that guides the system behavior.

From previous considerations, Figure 3 illustrates the proposed architecture over a B3G network. A DiffServ enabled IP network is assumed to be used in the core network. The key aspects of this QoS management architecture are the following:

- The PDF function already introduced in 3GPP R5/R6 policy framework is maintained and two new entities are introduced in the B3G QoS architecture: the Bandwidth Broker (BB) and the wireless QoS broker (WQB). The

BB [7] is in charge of the control plane of the DiffServ domain while the WQB is the counterpart of the BB for the radio part of the access network. A clear parallelism can be done between the WQB and the BB. These two entities share the same functionalities. They act both as policy decision points: the admission control and the handover decision (respectively at radio and IP level) are based on the network operator policy. Both entities are explained in next sections.

- BB and WQB can both act as policy managers and their policies are enforced in the core network routers as well as in the radio equipment respectively.
- Relationship between the PDF from IMS and the new entities WQB and BB is envisaged in terms of QoS negotiation. Furthermore this QoS negotiation is extended from the PDF, which really acts as a master PDP (M-PDP) of the domain, towards external neighboring domains [2].
- The proposed architecture is valid for any degree of coupling among the heterogeneous RANs. Thus, functions envisaged for the WQB entity are the same either in a tight coupling scenario with integrated CRRM functions or in the case of independent RAN from the radio resource management perspective, although the commitment of these functions and the interaction between QoS management entities would effectively depend on the degree of coupling.

Furthermore, B3G network architecture illustrated in Figure 3 also considers that SGSN control functions are separated from its data plane functions. Thus, in this architecture the RNC entity contains the IP stack (that otherwise should be located in the data plane of the SGSN) and then serves as an edge router to the CN. It is worth to remark that this assumption is not necessary to justify the proposed QoS management architecture since a SGSN entity can be introduced on the data path as currently envisaged in 3GPP release 5 and 6. In this latter case, SGSN would serve as a DiffServ edge router and a standard Iu-PS interface would be used to connect the RNCs to a given SGSN. The reason why it has been decided not to consider the SGSN on the data path in the proposed architecture is intended to demonstrate the feasibility of introducing native IP transport down to the RNC and its equivalents.

4.1. QoS Management in the CN: BB concept

The 3GPP does not specify a particular solution for the QoS management in the IP CN, leaving the choice to the operator among a plethora of solutions (IntServ with RSVP, MRSVP, NSIS, DiffServ, etc) Among the different QoS solutions it is thought that a DiffServ solution with a control plane based on a BB entity, by its centralized way of management, is an appropriate choice to coordinate the radio access BS, the CN BS and the external BS (the BS provided by the neighbor domain) in order to provide an end-to-end service to the user. Moreover, the BB can be considered as a policy-based manager as it performs in some measure policy management functions. That is, regarding the IP resources in the CN, it performs policy-based admission control based on the operator policy and it can dynamically configure the edge DiffServ routers of the CN through the COPS protocol [5]. Thus, the BB can equally be regarded as a Policy Decision Point (PDP) for the IP QoS in the CN.

4.2. QoS Management in RANs: WQB concept

The Wireless QoS Broker entity can be seen as the counterpart of the BB for the radio part of the access network although functions deployed may have a completely different approach due to the specific characteristics of the radio access part. The envisaged functions for the Wireless QoS Broker entity are represented in Figure 4 and described hereafter:

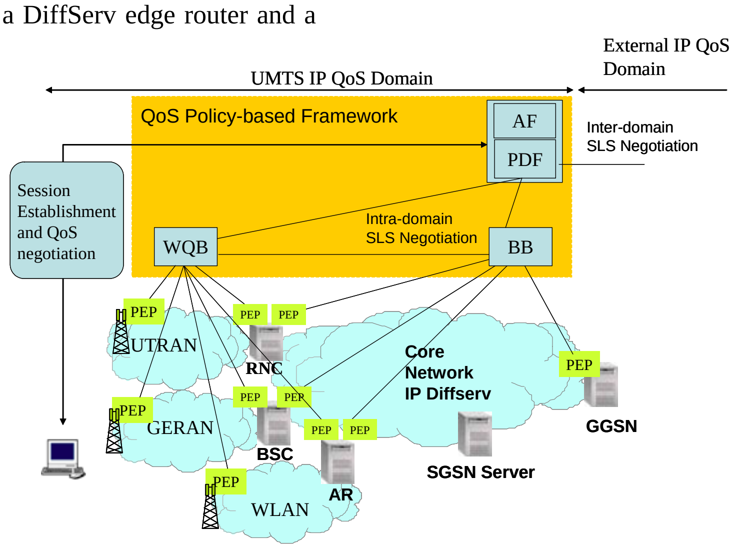

Figure 3. QoS framework for a heterogeneous radio access network

- Configuration of RAN elements for QoS provision. One function of the WQB is to act as a PDP in order to configure QoS mechanisms available at the RANs. As each RAN may have specific QoS mechanisms, the WQB will be responsible of the configuration of such mechanisms in order to achieve the expected behavior. In the case of UTRAN, QoS is provisioned by means of RRM strategies deployed in Node-B and mainly in Radio Network Controller (RNC). The key goal of introducing policy-based mechanisms relies on the capacity to configure the provision of certain QoS behavior by using a specific set of RRM parameters made "visible" to the policy framework. As an example of this function, work in [8] shows how the configuration of certain parameters in the admission control and packet scheduling at the radio level can influence the relative priority of guaranteed bit rate traffic and thus can be used as the basis to formulate the correspondent policies. This functionality is shown in the Figure 4 by the logical links drawn between the WQB and the RNCs, Node Bs and APs.
- Common Radio Resource Management. A CRRM function that is able to steer the traffic distribution among the RATs towards an optimal distribution provides a clear benefit by increasing the radio resource efficiency and improving the perceived service quality. The 3GPP specifications currently identify two possible approaches to support CRRM in UTRAN and GERAN [TR 25.881, TR 25.891]. Both 3GPP CRRM implementation visions can be included under the WQB concept since WQB may be implemented either in a centralized or a distributed approach. So, the WQB entity may handle some CRRM functions with different degree of coupling with the RRM entities of the different RANs and be the nexus between CRRM decisions and the B3G QoS management. It is worthy noting that WLAN is not included in the initial CRRM framework in 3GPP since there is no dedicated RRM entity in a typical WLAN architecture. Furthermore, how to couple WLAN with UTRAN/ GERAN is another issue to affect the CRRM solution. In any case, in the architecture envisaged here, the WQB entity would allocate two main functionalities related to CRRM: coordination of the different access resource pools, each with their own RRM functionalities and selection of the most suitable RAT through call admission control or inter-system handover procedures in terms of some operator defined policies.
- Intra-domain QoS negotiation. Coordination is needed between the WQB and the BB, as the admission control and handover decision are submitted to different constraints in the radio part and the IP CN of the mobile access network. In the first case these constraints are related to the radio resource usage, and in the latter case to the network topology and the traffic distribution in the network. In the precedent subsection, it has been said that the output of the CRRM may be for example the selected RAT. However this decision may not be optimal from the BB point of view: the target cell may correspond to an attachment point to the IP CN which may be congested. As a main strength of policy-based management, policies used to support the decisions taken in the QoS negotiation process can be formulated taken into account multiple criteria, not only radio resource optimization. Figure 4 already highlights which kind of information would be made available at each decision point.

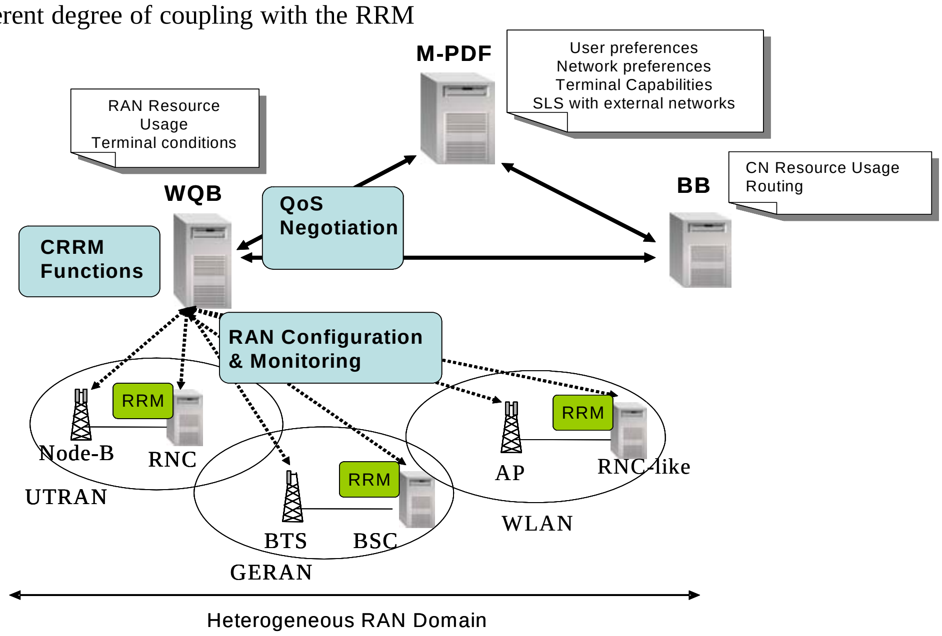

Figure 4. Envisaged functions for the proposed Wireless QoS Manager

5. Signaling Protocols for procedures definition

An end-to-end QoS architecture in a heterogeneous radio access network has been proposed in Section 4 from a conceptual point of view. The presented approach is claimed to be innovate as long as it is inspired in the most relevant trends being developed in different fields and forums and come up with a global solution capturing such partial concepts

Nevertheless, the conceptual development of an end-to-end architecture is only feasible from the implementation point of view if there are procedures and protocols supporting the required interactions. To this end, this section is devoted to elaborate this critical component, then demonstrating the practical feasibility of the proposed architecture.

5.1. QoS Signaling Protocols

As already pointed in Section 4, authorization of a SIP session in current 3GPP QoS Framework is done without taking into account network resources. Furthermore, the interception of the SIP messages in the IMS to get SDP information exchanged between end SIP user agents does not allow end-to-end encryption and integrity protection mechanisms to be used between SIP user agents. All these restrictions conduct to the need of a modified QoS negotiation mechanism to fulfill the following requirements:

- Authorize a session with a negotiated QoS taking into account the current status of the involved network domains.
- Introduce RAN selection capabilities in the procedure as well as any other information used in the decision process.

Both requirements should be incorporated in any proposed solution. So, the 2-phase signaling (i.e. SIP and PDP Context Signaling) should be modified accordingly to cope with them. However, in this paper, as our main interest is to show how the proposed WQB and BB entities may fit in the QoS framework, and additional signaling phase is considered between SIP and PDP context signaling. This intermediate phase is devoted to perform QoS negotiation coping with identified requirements. It is for further study how functions assigned to this “middle” phase should be partitioned and moved either up to the session establishment phase or down to the PDP context management.

According to previous arguments, the 2-level signaling scheme envisaged in IMS is extended by the addition of a policy-based negotiation phase as illustrated in Figure 5. As policy-based negotiation protocol (e.g. COPS-SLS [9]) uses the flexibility of the COPS protocol, it allows a negotiation specific to the policy of each domain. Each domain might have a specific set of negotiation parameters (or a set of SLSs) and specific policy for admission control. The set of SLS negotiation parameters may be specified following the IETF draft [10], nonetheless each domain has the possibility to select its own set of parameters, and implement its own policy for negotiation and admission.

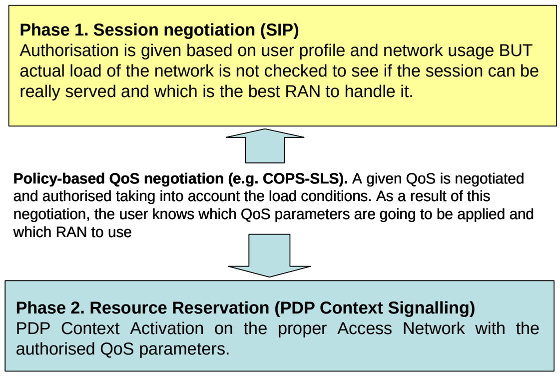

Figure 5.Protocols used in the QoS negotiation

5.2. Detailed Functional Allocation

According to the architecture illustrated in Figure 3 and previous considerations about QoS protocols usage, Figure 6 indicates how required functionalities are allocated within the main network entities. The following assumptions have been considered:

- No explicit SGSN server entity is considered for the sake of complexity. On the contrary, SGSN functions related to Session Management (SM) are assumed to be located in the RNCs. This assumption does not invalidate the usage of a SGSN server as identified in the E2E Architecture. In any case if QoS enforcement was considered from WQB and BB after a QoS negotiation, SM signaling (PDP signaling) would not be needed.
- An IP Mobility Management other than GTP solution can be used at CN (e.g. BCMP). So, Access Router functions would be located at RNCs whereas Anchor Point functionality would be located at the GGSN.
- A Master PDF (MPDP) entity exists in the B3G network domain as the visible entity for the users to carry out QoS negotiation. This M-PDF would also be in charge of inter–domain SLS negotiation.

5.3. Example: Connection Establishment Procedure

After reviewed the different entities of the access network, involved in the end-to-end QoS negotiation, the signaling occurring between these entities is examined. In particular we address the connection establishment procedure were an initial RAT selection procedure is involved. Message chart provided in Figure 7 illustrates how CRRM functions are expected to be used to allocate a session with E2E QoS guarantees over a B3G network.

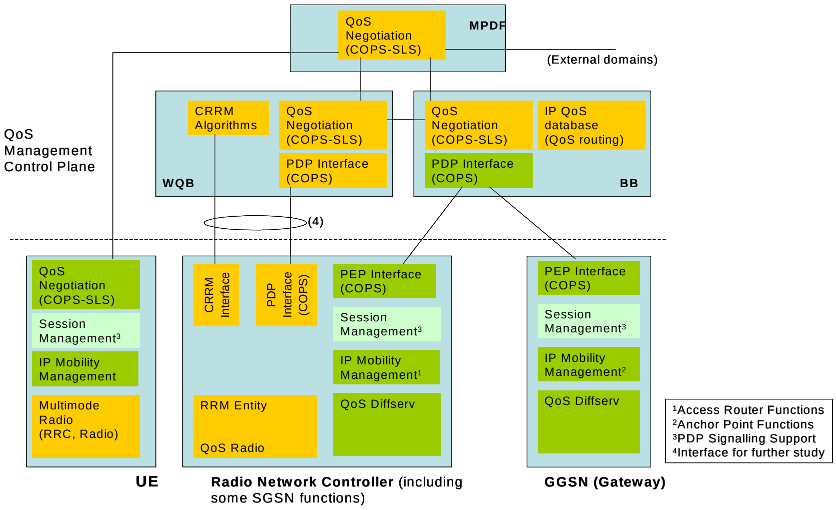

Figure 6. Main functionalities of the entities of the proposed QoS framework

The underlying architecture assumed in the message chart considers two radio network controllers (RNC1 and RNC2) of any of the considered technologies (UTRAN, GERAN and WLAN in case of tight coupling) directly connected to the CN as edge routers (see section 5.2. to justify this option). Steps identified in the message chart in Figure 7 are the following:

1. The user is connected to a given RAN by default. A RRC connection or similar is established through this RAN. This connection allows the RNC of this specific RAN to know about the radio conditions of that user as well as possible available access networks different that current (the UE can monitor these networks).
2. SIP signaling is done between end users. There is no need in the IMS to decode SDP contents but actually it is done to perform a policy-based authorization according to user subscription as well as general network usage.
3. A COPS-SLS session is initiated to negotiate required QoS for the session under way. A SLS is provided by the user according to the characteristics of the SIP session to be established. Notice that this signaling could also be triggered after the first message of next phase (i.e. PDP Context Activation request) so that the user would not be directly involved in COPS-SLS.
4. The Master PDF may perform a first decision of which RAT is the best appropriate for this user as well as which Access Point Name (i.e. GGSN) according to user subscription, terminal capabilities and preferences as well as operator preferences. As a result a prioritized list of candidate RATs can be generated. Also SLS agreements with external domains can influence on the decision of how QoS is provisioned within the B3G network domain. It is important to remark here that SLS negotiation with external domains is not envisaged at a per-flow level. Instead, aggregated SLS are assumed to be negotiated between domains.
5. The WQB is asked to support a given SLS. The list of candidate RATs according to MPDF decision process will be passed in this request.
6. The WQB triggers an Initial RAT Selection algorithm that forms part of the set of CRRM strategies held within this entity. To that end, the WQB obtains some information from the RNC the user is connected to (i.e. mobile speed, reported cells, position, etc.). Based on this information, and attending the provided list preferences, the algorithm generates a target cell of a specific RAT (it could also be a prioritized list of RATs) and the QoS it can offer taking into account that SLS request is going to be split among the CN and RAN domains. Admission Control (AC) in the involved RATs should be checked at this stage.
7. As the selection of a given RAT implies a given Access Router to be used (i.e. RNC in our case), the BB is requested to provide some QoS between this RNC (or the list of prioritized RNCs) and the target APN (or GGSN). So, the path between RNC and GGSN must be selected to provide the required SLS.
8. If the route between GGSN and RNC is possible, the BB accepts the request. The BB can implement an interface to the QoS routing used in the IP domain.
9. The WQB forwards the decision up to the MPDF
10. The user is granted access through a given RNC (e.g. RNC2 in the message chart) with a given QoS and an authorization token needed in the resource reservation phase. Notice that if the user does not participate in the COPS-SLS signaling, as suggested in step 3, the user would not receive the decision about the target RAN. However, in this latter case, the user can be forced to move to the target RAN by means of standard handover mechanisms when setting up the PDP context.
11. When the SLS negotiation between the user and the access network QoS control management entities has been finished, the SLS has to be enforced at the user plane: in the RNC and the GGSN. This enforcement is

triggered by the PDP Context signaling. A PDP Context Establishment is carried out to activate granted resources in the network. The PDP activation is coupled with a validation process against the WQB and the BB in the same way as the current solution in UMTS (the GGSN validates resources requests against the PDF by using COPS). Once the PDP Context Accept message has been received by the user, the radio bearer and the DiffServ edge configurations are established. Finally, it is also worthy to remark that we have chosen a specific mechanism for the negotiation between the WQB, BB and MPDF although other alternatives must be evaluated.

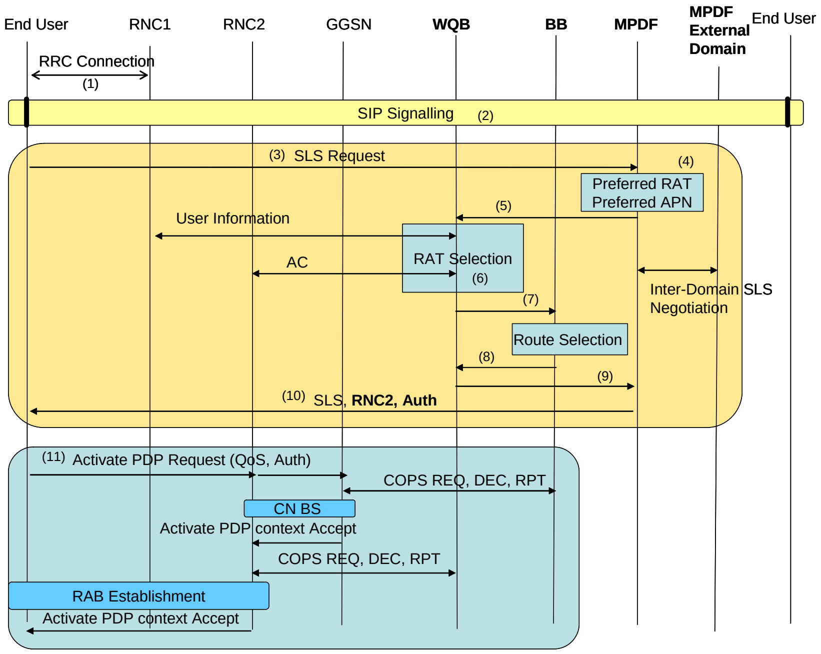

Figure 7. Connection Establishment over a B3G network with CRRM functionalities

6. Conclusions

This paper develops a QoS management architecture for B3G networks with CRRM functionalities. The proposed architecture extends the 3GPP QoS approach by introducing a new entity, the Wireless QoS Broker, which allows the effective radio resource management of the different radio access technologies which may co-exist in a B3G network. The WQB should be devoted to configure QoS provisioning mechanisms in the involved RAN, would directly apply or configure common radio resource management functions available in the radio part and would be in charge of QoS negotiation through admission control and inter-system handover procedures. Going a step further, the conceptual QoS architecture is developed in terms of the identification and allocation of involved functionalities among network entities as well as the specification of the protocols required to support interactions between these entities. This development aimed to demonstrate the practical feasibility of the proposed architecture is finally concluded with the specification of a connection establishement procedure.

Acknowledgements

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