QoS Control in Next-Generation Multimedia Networks

Overview of ITU-T NGN QoS Control

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Abstract

This article presents an overview of standards activities defining the QoS control architecture. Several standards bodies define the QoS control architectures based on their scope of work. This article first reviews the QoS control architectures defined in the standards bodies such as CableLab, DSL Forum, MSF, ETSI, and ITU-T. ITU-T NGN architecture provides the generic framework to cover the results of each standards body. Other architectures focus on solving specific problems. We explain in more detail the ITU-T QoS control architecture defined in resource and admission control functions (RACF) and discuss future standards developments.

Introduction

The Internet was originally designed for simple connectivity of best effort traffic. As Internet service expands its capability to support various types of service, such as voice, video, and interactive games, Internet users expect better quality of service (QoS). Service and network providers have invested large amounts of money to accommodate the dramatically increasing Internet traffic, and they want to squeeze the most profit as possible out of the Internet infrastructure. The Internet is considered as a foundation of a next generation network (NGN). NGN is evolving in the direction of a packet-based network for both real time and non-real time traffic. QoS is one of the main concerns in an IP network. Unlike the circuit-based network, the packet-based service lacks the control mechanism for end-to-end QoS.

There are ongoing efforts to achieve end-to-end QoS in an IP network. Compared to integrated services (IntServ) [1] that require every node to maintain the flow state, differentiated services (DiffServ) [2] are designed for the scalability of the Internet. The nodes in DiffServ operate without the flow state information. Traffic with similar characteristics is classified into a class. Each node provides class-based differentiated service. Although the scalability of the network is desirable, DiffServ has a genuine problem. It works properly only in the underload condition that cannot be guaranteed in a large network like the Internet. Research shows that DiffServ guarantees the maximum delay bound only when the network is significantly under loaded [3], and implementation complexity for assured service is high [4]. To overcome this short fall, many methods guaranteeing end to end QoS in DiffServ architecture have been studied. The flow level control is considered necessary in many approaches. France Telecom (FT) proposed a new architecture called flow aware network (FAN) [5] that combines IntServ and DiffServ. The flow aware edge node of FAN drops the packet of the misbehaving flow only when the network load exceeds a certain threshold. British Telecom (BT), Anagran, and the Electronics and Telecommunications Research Institute (ETRI) proposed flow state aware (FSA) technology [6] that defines the Internet service into several types and defines the requirements and the control procedures.

QoS control can be implemented in many different ways. For the purpose of interoperability, the QoS control mechanism should be defined in the same framework. A discussion about the Internet based NGN is progressing actively in the standards bodies, including the International Telecommunication Union — Telecommunication Standardization Sector (ITU-T), the European Telecommunications Standards Institute (ETSI), the Institute of Electrical and Electronics Engineers (IEEE), the Internet Engineering Task Force (IETF), and so on. The roles of the standards bodies are different. The IEEE and IETF develop the core technology for specific problems in layer 2 and layer 3, respectively. ITU-T and ETSI develop the network architecture and control procedures. In this article, we will review the QoS control architectures and procedures proposed in the standards bodies.

The QoS control or resource control architecture has been developed in several standards bodies. To name a few, they are ITU-T, ETSI, Cable Lab, and the DSL forum. Among those organizations, CableLab, DSL forum, and ETSI define the QoS control architecture in a particular case, while ITU-T defines the generic architecture that can cover the outcomes of other

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standards bodies. Later, we will review and compare the QoS control architectures defined in standards bodies. In this article, we provide an overview of NGN QoS control, especially for ITU-T NGN. The QoS control architecture of ITU-T will be explained in more depth. Future directions will be described.

COMPARISON OF QOS CONTROL ARCHITECTURES

In this section, QoS control architectures defined in five standards bodies — CableLab, DSL Forum, the 3rd Generation Partnership Project (3GPP), ETSI, and ITU-T — are reviewed and compared.

CableLab defines the dynamic QoS (DQoS) control architecture [7] for the hybrid fiber and coaxial (HFC) network. The architecture is designed for the uniqueness of the HFC network. In the HFC network, multiple cable modems (CMs) share an upstream channel to the cable modem termination system (CMTS). The bandwidth sharing is controlled based on a layer 2 medium access control (MAC) protocol called data over cable system interface specification (DOCSIS) [8]. The layer 2 level QoS guarantee mechanism is defined from DOCSIS version 1.1. The goal of the DQoS is to support the QoS guaranteed through the HFC network.

DQoS defines the procedure of the call set-up signaling and the dynamic QoS control on the DOCSIS interface. In the architecture, the call management server (CMS)/gate controller controls the call establishment. The guaranteed bandwidth between CM and CMTS is reserved dynamically during the call set-up signaling. The CMS/gate controller triggers the layer 2 or layer 3 QoS signaling to reserve the bandwidth in the HFC network by sending a command to CM, CMS, or the multimedia terminal adapter (MTA).

DQoS has been refined through versions 1.0, 1.5, and 2.0. Version 1.0 defines the basic call set-up signaling procedure for both embedded MTA and standalone MTA. The embedded MTA can initiate the dynamic layer 2 QoS signaling, and standalone MTA initiates IP level QoS signaling. Version 1.5 and 2.0 define the QoS control architecture when Session Initiation Protocol (SIP)-based call set-up signaling is used. DQoS 2.0 is defined especially for interoperability with an IP multimedia subsystem (IMS), which is the SIP-based call set-up architecture developed in the 3GPP. PacketCable multimedia [9] has been developed for simple and reliable control for the multimedia service over cable network. It defines the service delivery framework for the policy-based control on multimedia service. The simple procedure for time or volume based resource authorization, resource auditing mechanism, and security of the infrastructure are defined in PacketCable multimedia.

The DSL forum defines the resource control at the DSL (digital subscriber line) access network [10]. Unlike Cable network, a DSL modem is connected to the subscriber through the dedicated line. Layer 2 level dynamic QoS control between a DSL modem and a digital subscriber line access multiplexer (DSLAM) is not required. The DSL forum focuses more on resource control in the home network, especially resource control of multiple terminals behind the home gateway. In the DSL network, the home gateway in the home network and the bRoadband access server (BRAS) on the network side are the important network elements. The traffic control of the DSL network is based on the differentiated services at the upstream of the access network. The home gateway, the routing gateway (RG), classifies the data traffic into DiffServ or best effort traffic, and discriminates traffic type when it is going out to the network. The primary function of the BRAS is the Layer 2 Tunneling Protocol (L2TP) access concentrator (LAC) function. It aggregates the subscriber traffic and delivers to a network — that is, connects the access network and the network provider. The QoS control principle of the DSL network is the management base. Unlike DQoS in the cable network, it does not control QoS on a call-by-call basis. The class-based discriminated-service control rule is set up in the home gateway at configuration time. The network operators have the class-level traffic control capability of the remote home gateway.

The resource control architectures defined in the previously mentioned two standards bodies — PacketCable and DSL Forum — focus on a specific transport technology (i.e., HFC network and DSL network). Unlike these two, the resource and admission control functions (RACFs) of ITU-T [11] and the resource and admission control sub-system (RACS) [12] of ETSI define the resource control architecture in a more general aspect.

The QoS control architecture in both RACF and RACS are closely related with the 3GPP effort. The 3GPP was originally founded for developing new service architecture over cellular networks, especially for the global system for mobile communication (GSM) network. During this effort, the 3GPP developed the IP multimedia subsystem (IMS) for controlling the IP multimedia services in the areas of session control, service control, and subscriber database management. Even though IMS was initially developed for the evolution of GSM cellular networks, its framework can be applied to any type of transport technology. The IMS architecture has been adopted by the other QoS control architectures, such as 3GPP2 multimedia domain (MMD), ETSI Telecoms & Internet converged Services & Protocols for Advanced Networks (TISPAN), and ITU-T NGN. Thus, both RACS and RACF are interoperable with IMS.

In general, RACF and RACS are very similar. The two standards bodies closely interacted in developing their architecture. There is no significant conflict between the two, but there are still differences [13]. One of the differences is the range of the control region. The control region of RACS covers the access network and the edge of the core network. The access network is defined as the region where the traffic is aggregated or distributed without dynamic routing. The resource control in the access network is done in the layer 2 level. The core network is

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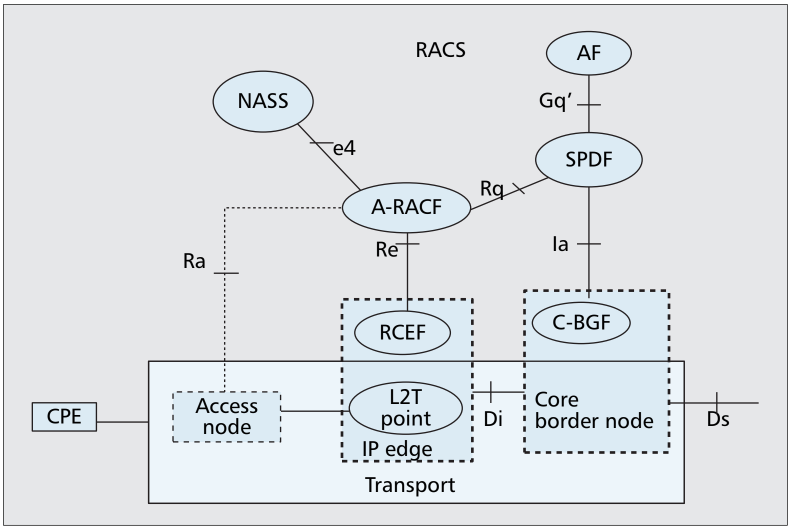


■ **Figure 1.** *RACS functional architecture.*

the region where the IP routing starts. The core network is out of the scope of the RACS. The RACF, however, covers both the core and the access network. The RACF covers both fixed and mobile networks while the RACS is defined for the fixed network. For the control mechanism, the RACF defines more control scenarios than the RACS does. Therefore, the RACS is considered as a subset of the RACF [13].

Figure 1 shows the functional architecture for the RACS. In the RACS, the QoS control is made in layer 3 (i.e., the IP level), which is independent of the transport technologies. The RACS defines how to control the IP edge node that is located at the boundary of access and core. The network element at the layer 2 termination and the network element positioned at the boundary of the core network are the two QoS enforcement points. Access resource and admission control functions (A-RACF) make the admission decision based on the resource state of the access network, and the service-based policy decision function (SPDF) performs the policy-based decision and the control of the edge of the core network. Because the scope of the RACS does not include the core network, it is not necessary to have the topology information of the core network of the RACS. QoS control is performed in push mode where the QoS control function (A-RACF and SPDF) sends the command to the transport equipment. Details for the push mode and the pull mode control scenario will be explained in the next section.

ITU-T defines the QoS control functions based on its NGN architecture. One of the important concepts in the ITU-T NGN architecture is the independence of the transport and the service [14]. The transport is concerned about the delivery of any type of packets generically, while the services are concerned about the packet payloads, which may be part of the user, control, or management plane. In this design principle, the NGN architecture is divided into two stratums — the service stratum and the transport stratum.

The transport control function is located in the transport stratum that interfaces with the service stratum. It determines the admission of the requested service based on the network policy and the resource availability. It also controls the network element to allocate the resource after it is accepted. The RACF is responsible for the major part of the admission decision and the resource control of the transport function.

Table 1 summarizes the QoS control architectures. Different control methods are designed for the region of the network or the transport technology of the network. The QoS control mechanisms can be static or dynamic. In a static QoS control architecture, the QoS control information is stored in the configuration file of the network device. The initial QoS setup is applied to the device when the network device is powered-on or when the management system changes the configuration. A typical example of the configuration-based QoS control can be found in the DSL forum architecture. The QoS setup in the home gateway is determined by the configuration file or remote management system.

In the dynamic QoS control, the requested QoS is provided dynamically. Voice over IP (VoIP) service, for example, is established by

	Control Region	Transport technologies	Static or Dynamic	Feature
ITU-T RACF	core network, access network	Transport technology independent	Dynamic	Call level control and the aggregate level traffic control QoS control for both the core and access network
ETSI RACS	Access network, edge of the core network	Transport technology independent	Dynamic	Call level control Access network and edge of the core network
3GPP	Access network	GSM network	Dynamic	IMS based session and service control
PacketCable	Access network	Cable network	Dynamic + Static	Combine the call setup signaling and control of the cable transport access network.
DSL forum	Access network	DSL network	Static	Configuration based QoS control Differentiated service using DiffServ

■ **Table 1.** *Comparison of resource management architectures.*

dynamic call setup signaling. Network resource control must be performed during the call set-up signaling. The QoS architecture defined in ETSI and ITU-T, assumes the independence of the service stratum and the transport stratum. In this case, the requested QoS from the application signaling can be dynamically changed, and the transport architecture must be able to reserve network resources for the QoS request. The architectures defined in ITU-T and ETSI focus on dynamic QoS. CableLab defines both aspects. Primary services can be established at configuration time. Dynamic addition of service also is possible by the QoS signaling. DQoS defined in PacketCable defines the dynamic aspect of the QoS control. The RACF and the RACS also consider the characteristics of the DSL environment in their development so that they can be directly applied to those environments to achieve dynamic QoS control.

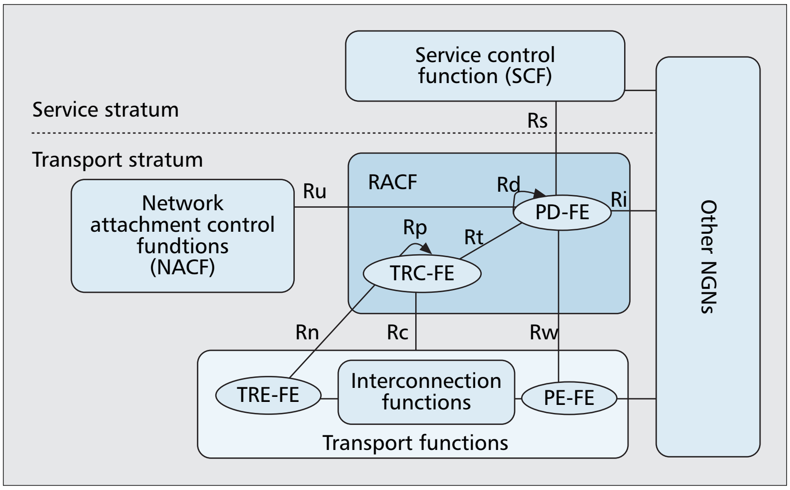


Figure 2. *RACF functional architecture.*

Overview of ITU-T RACF

As explained in the previous section, the ITU-T NGN QoS control architecture covers the broad aspect. Its QoS control architecture and procedure is defined in [11]. In this section, detailed information on RACF is provided.

As mentioned previously, one of the important concepts in IUT-T NGN architecture is the independence of the transport stratum and the service stratum. For example, in the case of the Skype service that provides VoIP service, the voice traffic passes through the Internet network after the call set-up signaling is made between the host and the signaling server. The voice traffic passes through the network operated by a certain network operator (e.g., Verizon). However, the network provider cannot profit from the premium traffic passing through its own network. The service provider also has a problem in deploying the high quality service, because no QoS request/guarantee mechanism is available from the network side.

To solve this problem, ITU-T NGN assumes the independence between the service and the transport. Under the concept of the independence of the service and transport functions, the required network resource and service reliability are provided by the network side upon request from the service stratum. The service stratum is responsible for the application signaling, and the transport stratum is responsible for reliable data-packet forwarding and traffic control. The service stratum can be a simple application server or a full-blown system such as IMS.

The transport control function serves as an arbitrator connecting the two stratums. It determines the admission of the service request based on the network resource state and the policy of the network provider. It also controls the network equipment to allocate the actual resources in the network. The RACF is the function that determines the availability of the resources and appropriately controls the network element. The functional architecture of the RACF is described in Fig. 2 [11].

The service control function (SCF) is responsible for the application signaling for the service setup. An SCF sends the QoS request to the RACF. The RACF determines whether the requested QoS is acceptable and then controls the network element to reserve the resource in the network. A network attachment control function (NACF) supports the user QoS profile authorization in the access network. In the call set-up procedure, NACF checks the request based on the maximum bandwidth of the access network subscribers. The functional architecture is developed on a location-independent principle, that is, the same functional architecture of the RACF is applied to both the access network and the core network.

The RACF has two functional entities — the policy decision functional entity (PD-FE) and the transport resource control functional entity (TRC-FE). The PD-FE determines the acceptance of the request service based on the access network user profile, the service level agreement (SLA), the network operation policy, the service priority information, and the resource availability. After the request is accepted, it sends the traffic control information (e.g., the gate control, filtering, marking, shaping, and policing) to the transport equipment for allocating the resource in the network element. The PD-FE controls the transport device called the policy enforcement functional entity (PE-FE). The PE-FE is located at the edge or boundary of the regional network. In a real network, the PE-FE can be implemented in different forms such as session border gateway, CMTS, edge router, and so on. The PD-FE controls the QoS of the network by controlling the PE-FE positioned at the network boundary.

The TRC-FE monitors the network topology and the resource state of the regional network. It performs a resource-based admission decision. The TRC-FE is designed for controlling the transport technology dependent aspect, while the PD-FE is responsible for the technology-independent aspect. The current version of the RACF defines QoS control in the transport independent aspect (i.e., the IP level). No layer 2 control function has been defined in the TRC-FE yet. A continuous effort is under way to extend its scope to define the transport dependent control capability in TRC-FE. For example, The TRC-FE monitors the network topology and the resource state of the regional network. It performs a resource-based admission decision. The TRC-FE is designed for controlling the transport technology dependent aspect, while the PD-FE is responsible for the technology-independent aspect.

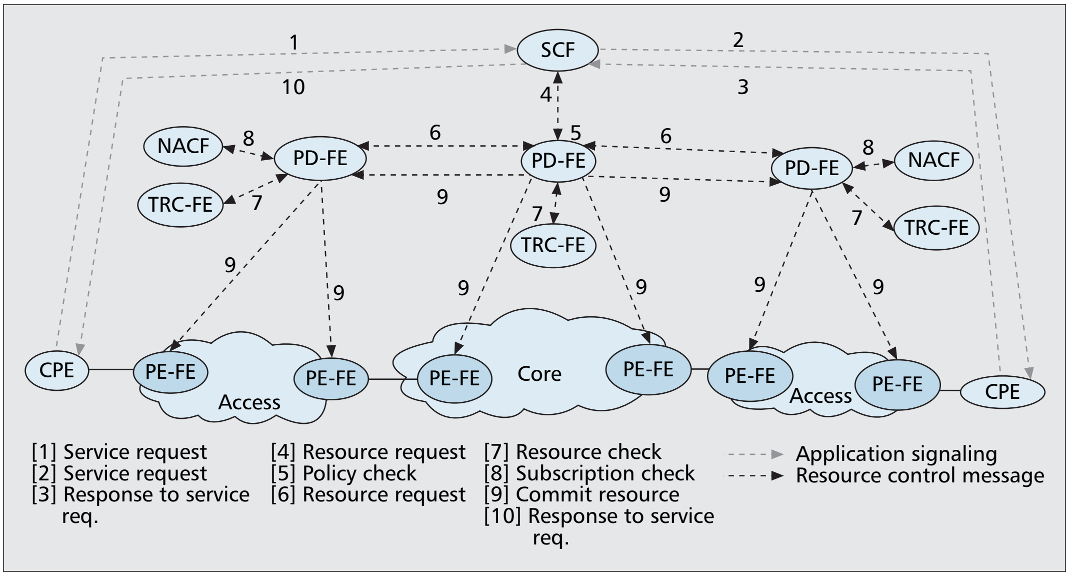


Figure 3. *Example of the end-to-end QoS control scenario in push mode.*

the multiprotocol label switching (MPLS) core network label-switched path (LSP) set-up triggering role of the RACF has yet to gain wide acceptance among network providers and is under discussion in [15].

For the protocol development, reference points are defined between the functional entities. Protocol selection has been completed for most of the reference points. The protocols for the reference points of Rs, Rp, Rw, Rc, and Rt are Diameter, Resource Connection Initiation Protocol (RCIP), Common Open Policy Service (COPS) protocol for support of policy provisioning (COPS-PR), H.248, and Diameter, COPS-PR, simple network management protocol (SNMP), and Diameter, respectively. Note that multiple protocols are defined for Rw and Rc. The protocol of the other reference points (e.g., Rd, Ri, Rn) are not determined yet. The summary of the protocol development of the reference points can be found in [16].

The RACF defines the QoS control scenarios for the user terminals and the customer premise equipment (CPE) with the various QoS signaling capabilities. The user terminal is classified as one of the following three types:

- Type 1: a terminal that does not have QoS signaling capability
- Type 2: a terminal recognizing the service level QoS (e.g., SIP terminal with QoS capability)
- Type 3: a terminal with path coupled QoS signaling capability (e.g., RSVP)

QoS control can be done either in pull mode or in push mode. In push mode, the PD-FE sends the QoS policy to the transport equipment (PE-FE) once the QoS request defined is received from the SCF. In pull mode, the PD-FE receives the QoS request from the PE-FE after the PE-FE receives the QoS request from the path-coupled QoS signaling. To support both push and pull mode, the Rw reference point between the PD-FE and the PE-FE should be bidirectional.

The type 1 and type 2 terminals are controlled in push mode, and the type 3 is controlled in pull mode. The QoS requirement of a type 1 terminal is determined in SCF, because a type 1 terminal cannot specify the QoS information in a signaling. Type 2 has the QoS requirement already defined in a signaling when it requests a resource.

An exemplary QoS control scenario in push mode is illustrated in Fig. 3. The explanation of each step is as follows.

1 The CPE sends the service requests to the call signaling server. In this request, a QoS parameter may not be specified if the CPE is type 1. In this case, the SCF should determine the QoS parameter in the application level.

2 The SCF function identifies the IP address of the terminating CPE and sends the service request. To identify the destination address, a proxy call signaling server may be involved.

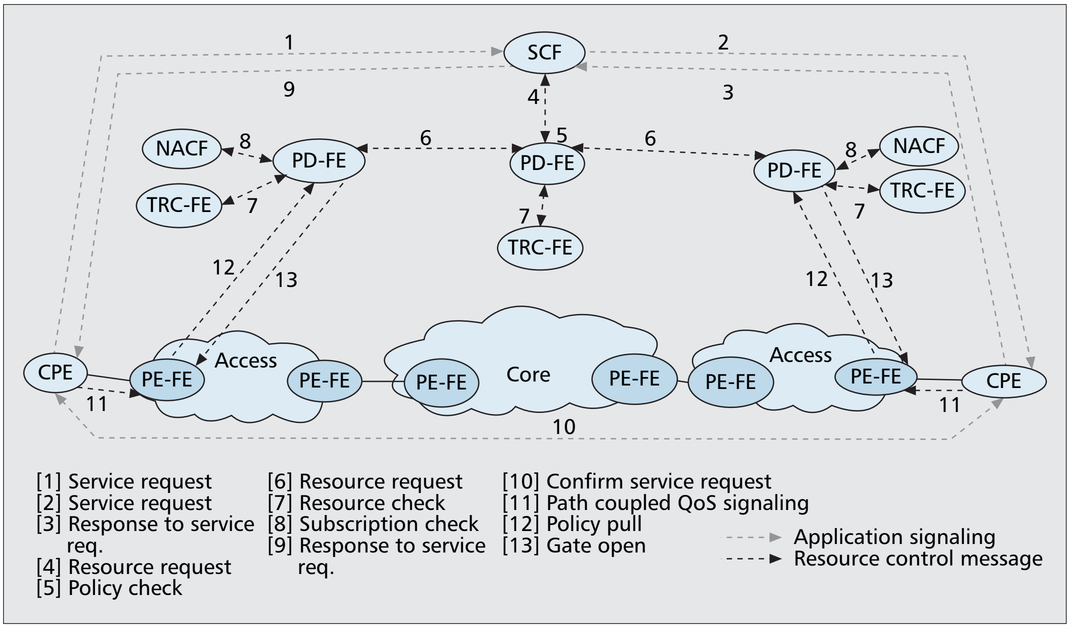
3 The terminating CPE responds to the service request.

4 The SCF sends a resource request to the PD-FE of the core network. The resource request contains the QoS requirement. This figure assumes that the SCF obtained the address information of the destination CPE. When the SCF sends the resource request to the PD-FE, the source and destination IP addresses are specified in the message.

5 After receiving the request, the PD-FE makes an admission decision based on the network operator's policy.

6 If the request is acceptable in the core network, the PD-FE of the core sends a request to the PD-FE of the access network to verify the decision of the access network.

7 The PD-FE of the core and access networks checks the resource availability from the TRC-FE that is monitoring the resource status of the network region and responds to the resource check request. Note that the admission decision is made in the two functional entities — PD-FE and TRC-FE. The PD-FE makes the policy based deci-



■ **Figure 4.** *Example of the end-to-end QoS control scenario in pull mode.*

In the PE-FE, the path-coupled signaling can be implemented in a termination, snooping, and proxy mode. For scalability purposes, the path-coupled QoS signaling can be implemented in termination mode or proxy mode.

sion and the TRC-FE makes the resource based decision.

8 In the access network, the PD-FE confirms to the NACF that the requested QoS does not exceed the authorized maximum bandwidth defined in the access network user profile. The subscription check to NACF may not be necessary if the information is pushed to the PD-FE when the CPE is attached to the network.

9 After the results of the policy check, resource check, and subscription check are confirmed as acceptable, the PD-FE controls the PE-FE at the boundary of the regional network.

10 After the SCF receives the response of the resource request in step 4, it sends the response to the service request.

The procedure described previously is a single feasible scenario. Other ways to perform QoS control also are possible. For example, a single PD-FE can be responsible for both access and core networks when they belong to the same network operator. For another example, the SCF can communicate with multiple PD-FEs in the access and core networks to avoid the inter PD-FE communication between two network providers. The physical location of the functional entity depends on implementation. Multiple functional entities can be implemented in the same physical entity. A session border controller (SBC), for example, often combines the SCF, PD-FE, and PE-FE in a physical device.

Push mode requires only the application level signaling capability for the CPE. Therefore, the control procedure is simple. When the CPE has path-coupled signaling capability (i.e., type 3), the QoS control can be performed in pull mode. Figure 4 explains the QoS control scenarios in pull mode. In pull mode, the QoS control is performed in two phases — pre-authorization and resource allocation. Following steps 1–9 in Fig. 4, application level signaling is completed in the same way as in push mode. During these steps, the requested service is pre-authorized. The CPE may receive the authorization token in the response of the service request in step 9. After the sender receives the response, the source and destination CPE can exchange the service request confirmation in step 10 before starting the path-coupled signaling. In step 11, the CPE initiates the path coupled QoS signaling. After receiving the QoS request, the PE-FE sends the QoS request to the PD-FE to check if the service has been authorized. The CPE may send the authorization token in the path-coupled signaling message. In this case, the PD-FE can simply check the token value to confirm the pre-authorization of the request. After the PD-FE confirms the authorization, it sends the gate control to the PE-FE to open the gate and allocate the resource. In the PE-FE, the path-coupled signaling can be implemented in a termination, snooping, and proxy mode. For scalability purposes, the path-coupled QoS signaling can be implemented in termination mode or proxy mode. The example of Fig. 4 assumes the termination mode where the first edge node (PE-FE) terminates the QoS signaling and performs the policy pull QoS request to the PD-FE. Proxy mode also can be used to reduce the signaling overhead. In this case, the PE-FE can aggregate and de-aggregate the QoS signaling message.

The procedure of resource control in pull mode is more complex than in push mode. As we can see in Fig. 4, the resource control in pull mode is performed in two phases — pre-authorization and resource allocation. Pull mode also requires the path-coupled QoS signaling capability of the CPE. However, the network resource can be utilized more efficiently in pull mode, because the network resource is reserved in the second phase after finishing the application signaling.

The RACF also defines the network address and port translation (NAPT) control function.

Several control architectures have been developed for supporting the QoS in the packet-based network. ITU-T RACF provides the general architecture covering both access and core networks. The current RACF specifies the functional architecture and control procedure in the IP level.

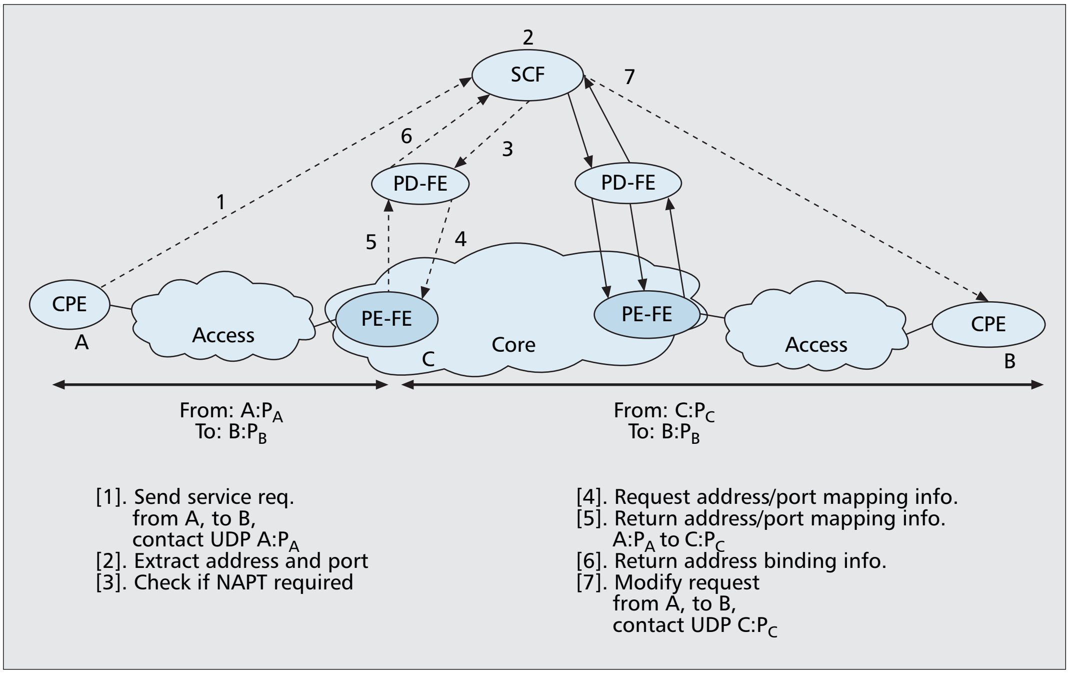


Figure 5. *Control procedure for NAPT control.*

Based on the network policy, NAPT is used to hide the network address details or to resolve the shortage of address space. The SCF is responsible for changing the address information in the application signaling. The PD-FE checks if NAPT control is required and controls the edge device (PE-FE) to modify the IP address of the data packet. Figure 5 shows the NAPT control procedure in RACF architecture. The figure shows the case when two hosts (A and B) communicate with IP addresses A and B and User Datagram Protocol (UDP) port number PA and PB respectively. By the NAPT control, the address:port of the data traffic A: PA is mapped to the other, C: PC, at the PE-FE. The SCF performs the signaling relay function to change the source address:port information in the message. Figure 5 shows the case when the NAPT device is under the network operator's domain (near end). In the case of the far-end NAPT traversal, the PE-FEs act as the media relay functions and modify the data stream to pass through the pin hole of the remote NAPT device.

Future Work on NGN QoS Control

Several control architectures have been developed for supporting the QoS in the packet-based network. ITU-T RACF provides the general architecture covering both access and core networks. The current RACF specifies the functional architecture and control procedure in the IP level. There are still many open issues, and continuing effort is under way to solve the issues.

QoS control in the transport technology-dependent aspect is one issue. The transport resource enforcement functional entity (TRE-FE) and Rn reference point described in a dashed line in Fig. 3 is created mainly for the transport-dependent control. In the RACF release 2 effort, functions of the TRC-FE, the TRE-FE, and the Rn reference point will be refined. QoS control mechanisms for several transport technologies will be defined for the core MPLS network [15], flow-state-aware technology [6], and Ethernet technology [17]. Having a unique transport technology, it is mandatory to consider a general framework for flow aggregation and signal aggregation. The granularity of flow aggregates and signal aggregates varies a great deal from network to network. The general framework for flow aggregation and signal aggregation is one of the major issues for the overall QoS architecture.

The high complexity and scalability of the control mechanism is another issue. Since the QoS control signaling is on a per-call basis, the QoS control in the core network will be a burden. For real implementation, the complexity of the QoS control should be optimized. To reduce the complexity, the part control function can be embedded in the transport equipment or combined with the management function. The QoS control mechanism can be simplified by using the performance monitoring information in the core network. For example, the call-by-call QoS control mechanism can be activated only when the network monitoring system detects that the performance degrades.

The reliability and security in the core network is another issue. For the control scalability of the network, traffic in the core network should be managed at the aggregate level. The defect in the core network will affect a wide region. Unlike the traditional circuit transport network, the IP does not have an embedded reliability feature. ITU-T NGN tries to improve an unreliable packet network. The transport MPLS (T-MPLS) and Ethernet operation, administration, and maintenance (OAM) are being defined to improve the reliability and enable the monitoring capability in the packet-based network.

For the new services such as fixed mobile convergence and IPTV services, QoS control for mobility and the multicast condition must be developed. QoS control in a home network is another open issue for future QoS control.

ACKNOWLEDGMENT

The authors would like to thank the anonymous reviewers for their helpful comments and suggestions. This work was partly supported by the IT R&D program of MIC/IITA [2006-S-064-01, Research on BcN Network Engineering Technologies] and the IT R&D program of MIC/IITA [2005-S-097-02, BcN Integrated Network Control and QoS/TE Management].

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ADDITIONAL READING

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BIOGRAPHIES

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For the new services such as fixed mobile convergence and IPTV services, QoS control for mobility and the multicast condition must be developed. QoS control in a home network is another open issue for future QoS control.