

Scalable Network Architecture for Flow-Based Traffic Control

Jongtae Song, Soon Seok Lee, Kug-Chang Kang, Noik Park, Heuk Park, Sunghyun Yoon, Kyung Gyu Chun, Mi Young Chang, Jinoo Joung, and Young Sun Kim

Many control schemes have been proposed for flow-level traffic control. However, flow-level traffic control is implemented only in limited areas such as traffic monitoring and traffic control at edge nodes. No clear solution for end-to-end architecture has been proposed. Scalability and the lack of a business model are major problems for deploying end-to-end flow-level control architecture. This paper introduces an end-to-end transport architecture and a scalable control mechanism to support the various flow-level QoS requests from applications.

Keywords: Flow-based traffic control, network architecture, QoS, flow-state-aware (FSA) technology.

I. Introduction

Internet service or information and communication technology service is becoming available in many industry sectors such as health, finance, entertainment, education, and government. The demand for new services is increasing and more diversified services are expected as more people experience Internet service. The service demands of customers are dramatically changing.

In the past, the advancement of technology has created new Internet services. In the future, however, the demand of customers for new services will be the driving force of technology development. Therefore, predicting the direction of service evolution is important in deciding the direction of technology development. As indicated in [1] and [2], the industry power has shifted from providers to customers. Customers are no longer satisfied with the typical services designed by the service providers. The requirements for QoS are becoming more important for the Internet, in both routing [3] and traffic engineering [4]. Personalization of service is a key requirement for future services. The transport network framework should be flexible enough to meet this service requirement.

To satisfy the various service requirements in the common transport framework, continuous effort has been made in two main areas. The first area is the development of an architecture with independence between the service and transport functions. By having independent service and transport functions, a network can support any QoS request from any service provider. The framework of service and transport independence has been actively discussed in standard bodies, such as ITU-T and the Next Generation Network Global

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Jongtae Song (phone: +82-42-860-5789, email: jsong@etri.re.kr), Soon Seok Lee (email: sslee@etri.re.kr), Kug-Chang Kang (email: kckang@etri.re.kr), Noik Park (email: nipark@etri.re.kr), Heuk Park (email: parkh@etri.re.kr), Sunghyun Yoon (email: shy72@etri.re.kr), Kyung Gyu Chun (email: jkq@etri.re.kr), Mi Young Chang (email: changmy@etri.re.kr), and Young Sun Kim (email: sunkim@etri.re.kr) are with the Broadcasting & Telecommunications Convergence Research Laboratory, ETRI, Daejeon, Rep. of Korea.

Jinoo Joung (email: jjoung@smu.ac.kr) is with the Department of Computer Science, Sangmyung University, Seoul, Rep. of Korea.

Standards Initiative (NGN-GSI). The second research goal is the development of a flexible transport architecture to control traffic on an individual flow basis. The flow in the IP packets is defined by the combination of five-tuple of the IP header, that is, source address, destination address, source port, destination port, and protocol. With the flow-based control capability, the transport network can meet the diversified QoS requirement on an individual flow level.

Core technologies in flow-level traffic control such as flow level buffering, scheduling, policing, and shaping have been extensively studied, and many commercial products are already on the market. However, flow-level traffic control capable equipment is deployed mainly at the edge of a network. To support flow-level QoS, we need to have consistent network architecture not only in the edge node but also in the transit nodes along the flow path. The core and access network architecture should be designed differently since the traffic characteristics are different in the two types of networks. The control mechanism should be scalable to support a large number of flows. In this paper, we review the status of flow-based QoS control architectures and introduce a scalable network architecture and a control mechanism that can provide flow-level control capability.

In section II, we review the standard activities discussing QoS control and the independence of service and transport functions. In section III, we review the current status of flow-based traffic control technologies. In section IV, we introduce the scalable flow-based control architecture to support end-to-end QoS control. The conclusion is given in section V.

II. Review of QoS Control Architectures

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 toward the Internet-based next generation network (NGN) has actively progressed around the standard bodies, including ITU-T, IEEE, ETSI, IETF, and so on. The roles of the various standard bodies in this process differ. The IEEE and IETF are developing the core technology for specific problems in layer 2 and layer 3, respectively. ITU-T and ETSI are developing the network architecture and control procedure.

QoS control or resource control architectures have been developed by several standard bodies, including ITU-T, ETSI, Cable Lab, 3GPP, MSF, and the DSL Forum. Among those organization, CableLab, DSL Forum, 3GPP, and ETSI have defined QoS control architecture for particular cases while ITU-T has defined a generic architecture that can cover the outcomes of other standard bodies.

CableLab has defined the dynamic QoS (DQoS) control

architecture [5] for the hybrid fiber and coaxial (HFC) network. The control architecture is designed specifically for the HFC network. In the HFC network, multiple cable modems (CMs) share an upstream channel to the cable modem termination system (CMTS). The bandwidth control is based on a layer 2 MAC protocol called the Data over Cable System Interface Specification (DOCSIS) [6]. The layer 2 QoS guarantee mechanism is defined according to DOCSIS version 1.1. The goal of DQoS is to support QoS guaranteed service through the HFC network.

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

The DQoS architecture has been refined through versions 1.0, 1.5, and 2.0. Version 1.0 defines the basic call setup signaling procedure for both an embedded MTA and a standalone MTA. The embedded MTA can initiate the dynamic layer 2 QoS signaling, while the 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 setup signaling is used. Version 2.0 is designed especially for interoperability with the IP Multimedia Subsystem (IMS), which is the SIP-based call setup architecture developed by the 3rd Generation Partnership Project (3GPP). PacketCable Multimedia [7] has been developed for simple and reliable control for multimedia service over cable networks. It defines the service delivery framework for policy-based control of multimedia service. The simple procedure for time- or volume-based resource authorization, the resource auditing mechanism, and security of the infrastructure are defined in PacketCable Multimedia.

The DSL Forum defines resource control at the DSL access network [8]. Unlike cable networks, a DSL modem is connected to the subscriber through a 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 a DSL network, the home gateway in the home network and the broadband access server (BRAS) on the network side are the important elements. The traffic control of the DSL network is based on the differentiated services at the upstream of the access network. The home gateway function which is defined as a routing

gateway (RG) function, classifies the data traffic into DiffServ or best-effort traffic and differentiates the traffic before it goes out to the network. The primary function of BRAS is the L2TP access concentrator (LAC) function. It aggregates the subscriber traffic and delivers it to a network. That is, it 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 pre-configured in the home gateway at the time of configuration. The network operators have the class-level traffic control capability of the remote home gateway.

The resource control architectures defined by PacketCable and DSL Forum focus on specific transport technologies namely, the HFC and DSL networks. The scope of DQoS and DSL Forum is mainly defined within the scope of network operators. On the contrary, the resource and admission control function (RACF) [9] of ITU-T and the resource and admission control sub-system (RACS) [10] of ETSI define the resource control architecture more generally.

The QoS control architecture in both the RACF and RACS are closely related with the 3GPP effort. The 3GPP was originally founded to develop a new service architecture to be used over cellular networks, in particular, the global system for mobile (GSM) communication network. During this project, 3GPP developed the IMS for IP multimedia services in the areas of session control, service control, and the management of the subscriber database. Even though IMS was initially developed for the evolution of GSM cellular networks, its framework can be applied to any transport technology. The IMS architecture has been adopted in other QoS control architectures, including 3GPP2 multimedia domain (MMD), ETSI's Telecoms & Internet converged Services & Protocols for Advanced Networks (TISPAN), and ITU-T NGN. Thus, both the RACS and RACF are interoperable with IMS.

In general, the RACF and RACS are very similar. The two standards bodies have closely collaborated in developing their architectures. There is no significant conflict between the two, but there are still differences [11]. One difference is the range of the control region. The control region of the 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 performed at the layer-2 level. The core network is the region where the IP routing starts. The core network is outside the scope of the RACS. The RACF, however, covers both core and access network. The RACF covers both fixed and mobile networks, while the RACS is designed for fixed networks. For the control mechanism, the

RACF defines more control scenarios than the RACS; therefore, the RACS is considered a subset of the RACF.

ITU-T defines the QoS control functions based on its NGN architecture. One important concept in the ITU-T NGN architecture is the independence of the transport and service functions [12]. Transport is generically related to the delivery of packets of any kind, while services concern 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 strata: the service stratum and the transport stratum. Under the concept of the independence of service and transport functions, the network resource and reliability are guaranteed 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 is located in transport stratum interfacing 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 once it is accepted. The RACF is responsible for the major part of the admission decision and resource control of the transport function. Details of the RACF mechanism can be found in [13] and [9].

III. Review of Current Flow-Based Control Architectures

Flow-level transport technology is not a new concept. The core technologies for traffic management schemes in flow-level scheduling, policing, and sharing are already available in commercial products [14]. The deployment of flow-based control, however, is limited only to the edge of the network. Typical examples of flow-based control are traffic monitoring, packet inspection, PacketCable access, session border control, edge routing, and interworking between two networks. They are mostly standalone solutions at the edge of the network.

However, flow-level traffic control only at the edge cannot guarantee flow-level QoS. DiffServ-based control is considered a simple solution to provide QoS in the transit node, but DiffServ guarantees the QoS only if the premium traffic load is lower than 10% [15]. As the network size increases, the traffic condition dynamically changes and we cannot guarantee a low traffic load. Therefore, flow-level traffic control only at the edge cannot guarantee end-to-end QoS. On the other hand, having scalable control architecture for flow-level traffic control along the data path is a challenging issue because the number of flows in a network is huge.

Several schemes have been proposed to control traffic at the

flow level. This section reviews the traffic control mechanisms of the flow-aware network (FAN) and flow-state-aware (FSA) networks and identifies the issues.

1. Flow-Aware Network (FAN)

The flow-aware network (FAN) [16] proposed by France Telecom applies three different regimes based on the network status: the transparent regime, elastic regime, and overload regime. The transparent regime is applied when the network has no congestion at all. The elastic regime is applied when the network experiences occasional traffic congestion because of a few high-rate data flows. The overload regime is applied when the traffic overloads the link capacity in the network.

No traffic control is effective in the transparent regime. Traffic control is only effective in the overload or elastic regimes. In the elastic regime, the network enforces the bandwidth limit for every flow. Every flow is assigned the same amount of bandwidth. In the overload regime, new flows are blocked to protect existing flows. To reduce the control complexity, an implicit approach is preferred. That is, no signaling is required to control the network. Each node makes locally optimal decision based on local observation.

The main advantage of FAN is simplicity. It requires no signaling. Only implicit admission control is required upon congestion. Although the control mechanism is very simple, the network is remarkably stabilized in FAN. However, this architecture is designed mainly for network stabilization. Every flow is treated equally. To support various QoS requirements for individual flows, this architecture should be improved.

2. Flow-State-Aware (FSA) Technologies

The FSA scheme was developed to provide different QoS for individual flows. FSA defines the service types based on typical examples of Internet services [17], [18]: maximum rate (MR), guaranteed rate (GR), variable rate (VR), and available rate (AR). GR is designed for applications requiring guaranteed bandwidth for the entire duration of the flow. MR is designed for streaming media such as video and voice. AR is designed for data traffic flow where the application can setup the flow rate at the maximum rate that the network can currently support. VR is a combination of AR and MR. VR is designed to obtain a minimum response time for a transaction (such as a stock trade with minimum transaction time). The MR portion is for guaranteed bandwidth, and the AR portion is for using the available network resource. FSA divides the network resource into two portions: fixed rate (FR) and network rate (NR). FR is requested when a flow needs a fixed rate available during the service, and NR is requested when a flow sends buffered data using the available network bandwidth. Service

types GR and MR request FR, AR requests NR, and VR requests both NR and FR. The detailed requirements are defined in [17].

FR and NR are requested by signaling, and every node along the path configures its resource based on the requested FR and NR. For the call setup signaling, the source node and destination node exchange control messages. Figure 1 shows the signaling procedure for MR, GR, and AR. The ingress FSA (iFSA) and egress FSA (eFSA) exchange request, response, confirm, renegotiate, and confirm message requests for the transport resource. For MR, the iFSA sends the data traffic before receiving the response from the eFSA. MR is designed based on the concept of conditional guaranteed bandwidth [18], [19]. For GR, it needs to know the explicit start and ending times of the flow. Therefore, it sends confirm and close messages to acknowledge every transit node that reserves and releases the requested bandwidth. The service type AR is designed to use the available network resource. The iFSA and other FSA nodes continuously monitor the available network resource and adjust the NR accordingly.

3. Observations on FAN and FSA Architectures

Both FAN and FSA provide insight into flow-based traffic control. FAN shows that even very simple flow-level traffic control can stabilize the network efficiently. FSA shows that the network resource can be divided into FR and NR. It also indicates that the transit nodes should be controlled for end-to-end flow-level QoS.

However, the two approaches have outstanding issues. As previously mentioned, FAN is not designed to support the various QoS requirements of various services. Its main purpose is to stabilize the overall network performance. For this reason, FAN treats every flow equally. This may stabilize the transport network in general, but the network provider cannot generate additional profit because FAN cannot support services that require special QoS treatment. For this reason, it is hard to find a good business model.

FSA is designed to support the QoS requirements of various services. It can be implemented in both in-band signaling and out-of-band signaling. The in-band signaling procedure requires every node to exchange requests and responses. Requests need to be examined by the all transit nodes. The destination nodes generate response messages, and the source node finds agreed rates from the response messages. In this approach every node should maintain the flow state. Maintaining the flow state is an issue when the number of flows increases. One possible way to maintain the flow state is to reduce the signaling complexity and implement the flow state in the hardware.

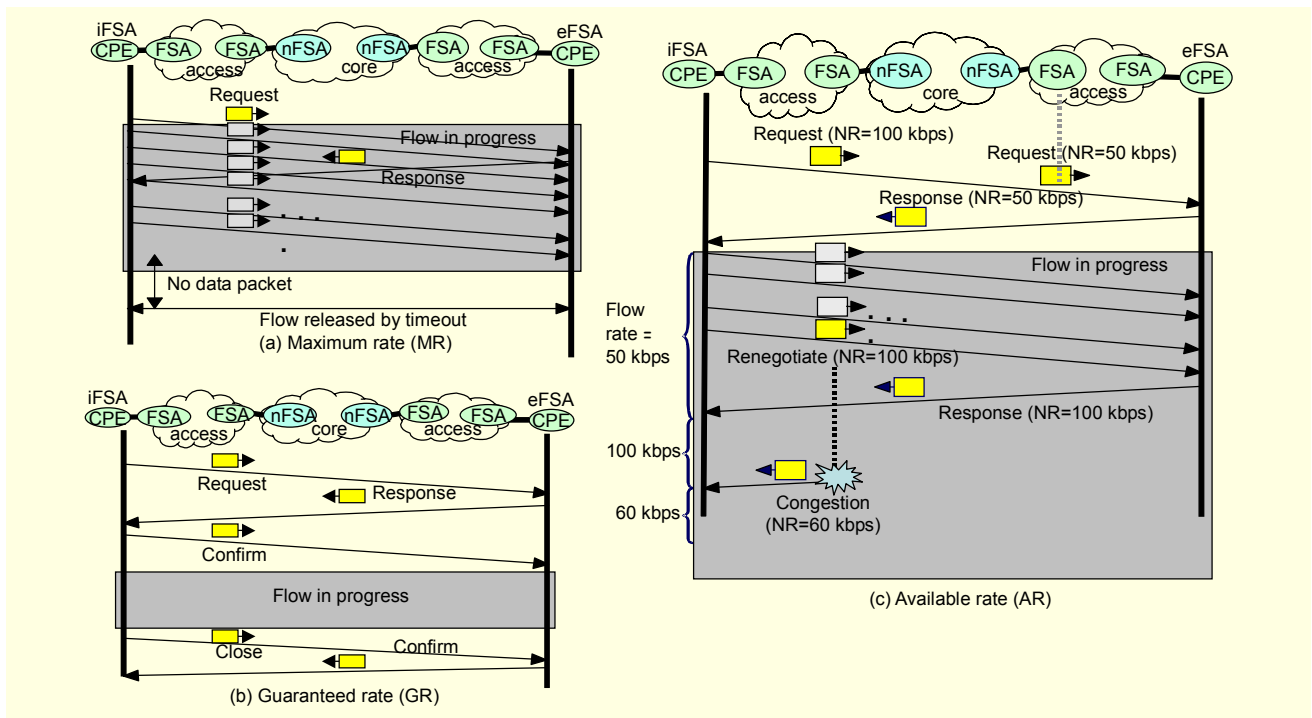


Fig. 1. FSA signaling procedure for each service context.

Requiring the FSA signaling feature in every user terminal is possible. However, making the terminal independent of FSA, has several possible benefits. First, different terminals have different capabilities. The network architecture should be flexible enough to support multiple types of terminals in a network. The terminal can support transport QoS signaling and application signaling. The application signaling is common for all terminal types. To support more terminal types, the QoS signaling of terminals should be designed at the application level. Network security is important in a managed network, so enabling the signaling function in the terminal may create a security hole in the network. To resolve this problem, [17] specifies the mechanism to authorize in-band signaling in the application signaling phase. Initiating FSA signaling on the network side from the network edge is another option to avoid this security problem.

In both FAN and FSA, the focus is mainly on transport control. To be more practical for business, the architecture should be coupled with the service level. The concept of RACF to interface between service and transport should be adopted.

IV. Scalable Network Architecture for Flow-Based Control

Many approaches have been proposed for flow-based control, including FAN and FSA. The advantage of FAN is the simplicity of the control mechanism. The advantage of FSA is

signaling capability in controlling transit nodes. To harmonize the two approaches and achieve an optimal solution, we can design a network architecture according to several design principles which are discussed in this section.

First, the transit node control is important but the signaling complexity should be minimized. In-band signaling requires all transport equipment to maintain the state of each flow. Full blown signaling capability requires software implementation, which creates overhead when the traffic volume and the number of flows increase. The complexity of signaling should be minimized to be implemented in a hardware solution. The customer premises equipment (CPE) or user terminal should be able to request the flow-level resource in any kind of application signaling. Therefore, the CPE should be independent from the transport protocol.

Second, the access network and the core network should be treated differently. In the access network, user data traffic is statically routed to the edge of the core network, and the downstream data traffic is statically forwarded from the edge of the core network to the end user. The core supports both IP-based dynamic routing and layer-2-based static forwarding. The traffic volume, number of flows, and dynamicity of traffic are different in the core and access networks. Traditionally, the access network controls the bandwidth based on subscribed bandwidth per user in the L2 level. For flow-level traffic control, however, the bandwidth should be controlled according to individual flows. Flow awareness capability is

required in the access nodes. Static packet forwarding and scheduling in the flow-level granularity is required in the access network. Call-by-call traffic control and policy enforcement from the control plane (RACF) should be done at the micro-flow level. In the core, the number of flows is high and call-by-call flow-level control in the RACF is difficult to achieve. In the core side network, therefore, the traffic should be controlled at the aggregate level rather than the micro-flow level. Reliability and monitoring capability are more important in the core. Flow-based traffic control and aggregated traffic control should be translated at the edge of the core network.

Third, the independence of the service and transport strata should be maintained. The independence of the service and transport functions is an important requirement for the network provider to have a good business model. For example, in case of Skype, which provides VoIP service, voice traffic passes through the Internet network once the call setup signaling is made between the host and the signaling server. The voice traffic passes through the network operated by a certain network operator (such as Verizon). However, the network provider cannot make any profit from the premium traffic passing through its own network. The service provider also has a problem in deploying high quality service because no QoS request/guarantee mechanism is available from the network side. Under the concept of the independence of the service and transport functions, the network resource and reliability are guaranteed by the network side upon request from the service stratum. This is important to enable businesses to make real profits by supporting various service requirements in the network. A network control function such as the RACF is necessary to connect the service and transport. Since the RACF interfaces with the service control function, which handles the application-level protocol, any kind of CPE can be supported. In-band signaling overhead can also be reduced by combining the RACF capability because the network resource state is checked in the network control plane.

Based on these three design principle, we developed our scalable flow-based network architecture. In this section, the architecture will be explained in terms of the access network, core network, and control mechanism.

1. Access Network

The access network supports flow-level traffic control. That is, the network equipment supports the flow-level QoS basis. The service context is defined at the flow level. The FSA service type, such as GR, MR, AR, and VR, can be used to define the flow-level QoS.

The FSA routers at the edge of the access network act as signaling proxies to handle the FAS QoS signaling capability.

Signaling complexity should be minimized. Signaling is only required at the setup time. The timeout of no packet transfer can automatically release the flow state in each node. The dynamic connection setup procedure is combined with the service-level application protocol. The RACF is necessary to interface between the service and transport functions. In the access network, the network topology is static, and the RACF can accurately check the resource state of the network. Handshaking signaling, such as response and confirm, may not be necessary in this case. Once the resource is authorized by the RACF, a one-way request is sufficient. Flow-level QoS information can be implicitly delivered using an IP header field such as DSCP. The QoS mapping policy from DSCP to flow-level QoS can be configured in the FSA routers. By reducing the complexity of full blown signaling capability to unidirectional request, the implementation complexity of in-band signaling to configure the transit nodes can be reduced. Therefore, the signaling functions can be implemented in hardware, and each node can maintain the flow state locally.

Figure 2 shows the procedure of the proposed in-band signaling. First, the CPE sends the service request to the service control function (SCF) that handles the application level signaling. The SCF decides the QoS parameters of the requested flow and sends the resource request to the RACF. The RACF checks the resource status of the network and the network policy. When the request is acceptable, the RACF checks the subscriber information of the user's maximum bandwidth. Once the resource, policy, and subscription checks are OK, the RACF sends the media flow information to the edge node to allocate the network resource and respond to the SCF.

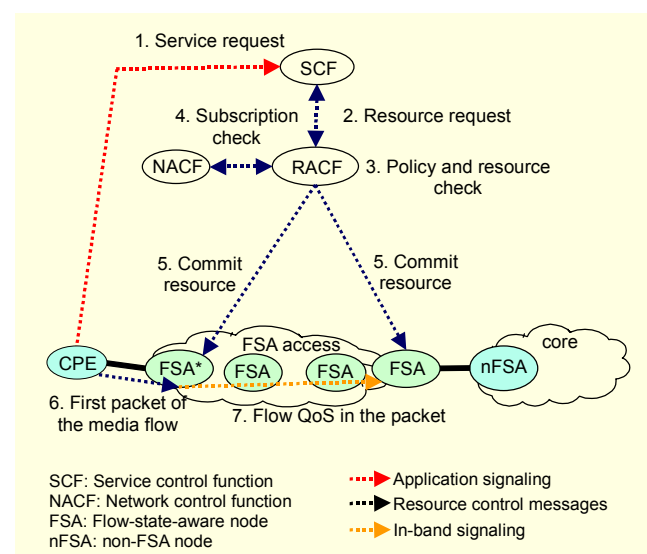


Fig. 2. In-band signaling simplified by combining RACF function.

From the start through the RACF checks (from step 1 to step 5 in Fig. 2), the control procedure is the same as that of the RACF push mode scenario. After finishing the checks, the flow-level QoS is installed at the edge devices. The CPE sends the media packet, once it receives the response of the service request. When the first edge node (indicated as FSA* in the figure) receives the packet, it triggers the QoS signaling to configure the flow-level QoS in the transit nodes along the flow path. The first edge node composes the flow-level QoS information and sends it along the same path as the media flow. The transit nodes receive the QoS information and configure their scheduler based on the received QoS information. The QoS information can be explicitly defined in a separate control message or implicitly embedded in the packet header (such as DSCP). Since the network resource has already been checked in the network control plane, handshaking messages, such as response and confirm, are redundant. One-way delivery of the QoS information is sufficient.

This procedure is mainly for processing dynamic QoS requests from call setup signaling (SIP-based service). For provision-based service (non-SIP-based service), the QoS profile is pre-defined in the transport by the management function.

2. Core Network

In the core network, the traffic condition is not dynamically changed as in the access network. MPLS is considered a good solution in the core network for its traffic engineering (TE) capability. Flows from the access network are aggregated into the pre-provided label-switching path (LSP) in the core network. Based on the network provider's policy, a network can aggregate the same type of flow into an LSP and a forwarding class. Performance and reliability of the flow is maintained at the aggregate level.

In addition to the TE capability, transport reliability is important in the core network. Link failure of the core network causes more serious problem than in the access network because each network link in the core network carries a huge volume of traffic. To support end-to-end QoS, the reliability and monitoring of traffic performance should be improved. When a failure occurs, the network should be able to redirect the traffic instantaneously. The OAM capability in an MPLS network is defined in transport MPLS (T-MPLS) [20], [21]. By aggregating the flow into the appropriate LSP, flow-based QoS and reliability of traffic can be achieved in the core network.

The call setup procedure should be simple. In the RACF of the core network, the number of service request is the sum of the number of requests of access networks. It is not practical to have call-by-call traffic control for the network devices in every

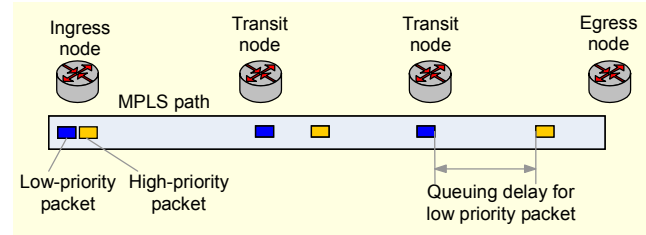


Fig. 3. High-level overview of DiffProbe.

flow request. The complexity of the control procedure can be reduced by utilizing monitoring capability. While the traffic condition does not change dynamically in the core, the network status should be constantly monitored to handle the occasional overload situation. Based on the network resource status, service requests are selectively accepted based on their service priority. For example, in an under-load state, service requests are accepted without any limitation. When the network becomes congested, only the highest preference service requests, such as emergency traffic, are accepted.

When congestion is detected or a connection request is rejected because of resource shortage, more LSP bandwidth is requested. The RACF monitors the network resource status through the management server and interacts with the TE server to request more bandwidth.

The performance monitoring function in the circuit switching network is mainly to detect high bit error rate or network failure. In the packet switching network, the traffic increment or instantaneous traffic congestion should also be detected by the performance monitoring mechanism. Delay performance is an important attribute. In the packet switching network, it is desirable to measure the delay performance without having global time synchronization. DiffProbe [22], [23] has been proposed to measure one-way delay and monitor the congestion of the network.

DiffProbe works over the DiffServe aware MPLS. Figure 3 shows the concept of the DiffProbe. The ingress node of the LSP sends a pair of OAM packets. One of the OAM packets is encapsulated in the supreme class, and the other is in the target class in the LSP. Then, they are transmitted to the destination back-to-back. After the ingress node of LSP sends the pair of OAM packets back-to-back, the egress node may receive the packets in a time interval. The traffic condition of the network and the per hop behavior (PHB) of the nodes along the LSP causes the delay difference between the two OAM packets. The inter-arrival time between the supreme class and target class packets captures the queuing delay of the target class packet because the delay of the supreme priority packet is mostly from the propagation delay, which is almost constant.

The relation between the inter-arrival time and the queuing

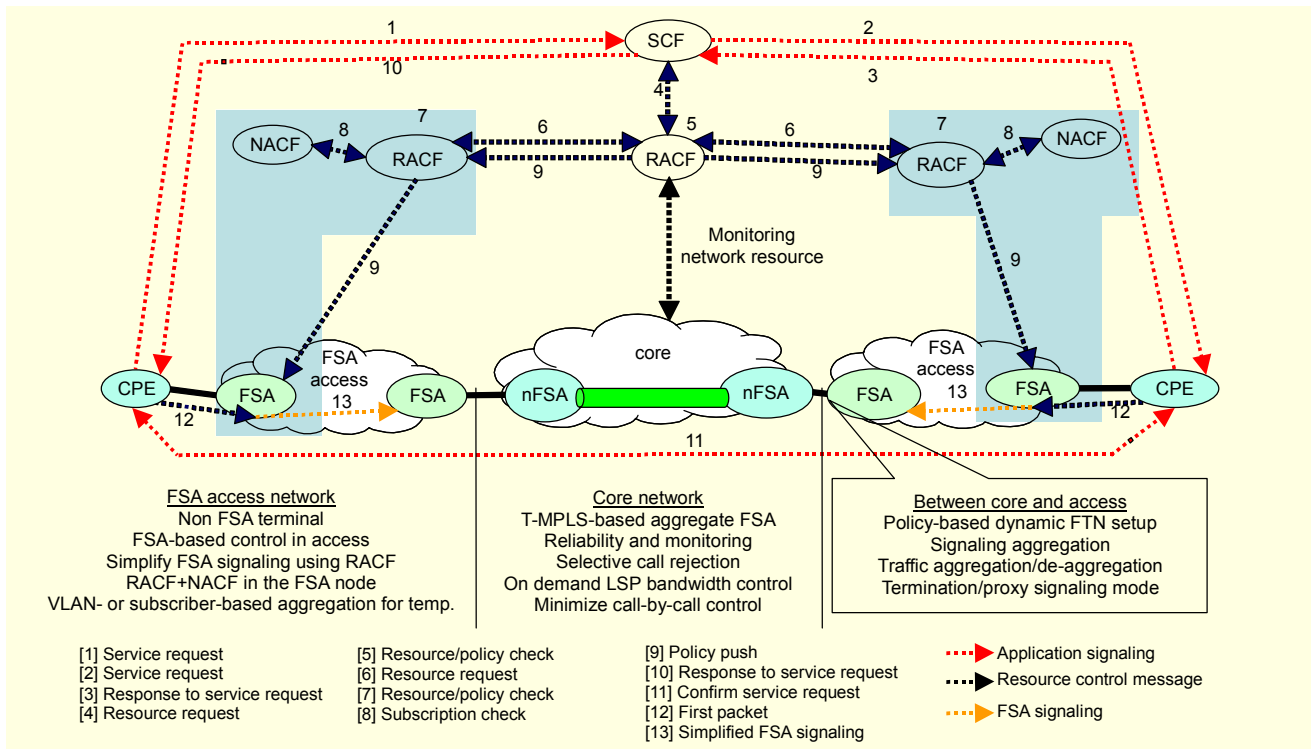


Fig. 4. End-to-end flow-based control procedure.

delay of the target class is described in [23]. When W_t is the average queuing delay of the target class, T_t and T_s are the delay of the target class and the supreme class respectively. The system utilization of the supreme class and the target class is denoted by ρ_s and ρ_t , respectively. The following equation holds:

$$T_t - T_s \approx W_t(\rho_s + \rho_t).$$

Therefore, the inter-arrival time of the two packets captures the average queuing delay of the target class when the total traffic load increases. Network congestion can be detected locally at the egress node without network level time synchronization.

3. End-to-End Control Procedure

As previously explained, the control mechanisms should be different in the access and core networks. In each case, the control mechanism should be defined in scaleable manner. The access network has a flexible architecture to support flow-level QoS on a call-by-call basis. The core network performs reliable traffic delivery and QoS monitoring at the aggregate level.

Figure 4 describes the end-to-end control procedure in the proposed network architecture. The procedure explains the end-to-end QoS control interaction. The details of the procedure can be explained in the following 13 steps.

Step 1. The CPE sends the service requests to the call signaling server. If the QoS parameters are not specified in the request, the SCF should determine the QoS parameter.

Step 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.

Step 3. The terminating CPE responds to the service request.

Step 4. The SCF sends a resource request to the RACF of the core network. The resource request contains the QoS requirement. In Fig. 4, we assume that the SCF obtains the address information of the destination CPE. When the SCF sends the resource request to the RACF, the source and destination IP addresses are specified in the message.

Step 5. After receiving the request, the RACF makes an admission decision based on the network operator's policy and resource status.

Step 6. If the request is acceptable in the core network, the RACF of core sends a request to the RACF of the access network to verify the condition of the access network.

Step 7. The RACF of the access network checks the resource availability and network policy. Since the topology is simple and deterministic in the access network, the RACF can estimate the accurate resource state along the path.

Step 8. In the access network, the RACF asks the NACF whether the request QoS exceeds the authorized maximum

bandwidth defined in the access network user profile.

Step 9. Once the results of the policy check, resource check, and subscription check are OK, the RACF of the access network sends the flow-level bandwidth information to the edge nodes of the access network. In this scenario, we assume that the topology of the access network is deterministic; therefore, accurate resource estimation can be performed in the control domain. When the RACF cannot support accurate resource estimation, the response to this should be sent after the resource availability is examined at the transport level.

Step 10. Once the SCF receives the response to the resource request of step 4, it sends a response to the service request.

After step 10, the flow-level QoS is installed at the edge devices.

Step 11. Once the sender receives a response, the source and destination CPEs can exchange the service request confirmation before sending data.

Step 12. The CPE starts sending the media packet.

Step 13. Once the media packet is received at the first edge FSA node, the FSA node sends the flow-level QoS information along the data path. The QoS information can be either explicit control messages or implicit information, which is embedded in the IP header.

The key ideas of the network architecture are summarized in Fig. 4. For the access network, the focus is flow-level control capability. Using this architecture, call-by-call control is only needed at the first edge node in the access network, where the number of calls is reasonably small. To reduce the implementation complexity, RACF and NACF can be implemented in the same physical FSA router. Nodes in the legacy access network do not have flow-level control function and only support L2-level traffic control. In this case, L2-level priority or subscriber-based traffic aggregation may be used as a temporary solution.

In the core network, carrier-level stability is provided by T-MPLS-based flow aggregation. Reliability and monitoring capability are important for aggregate traffic control. Call-by-call control interaction between control function and network devices needs to be minimized. Based on the network resource status, service requests are accepted selectively based on the service priority. Admission control in the core is performed in the control plane without controlling the network devices. The bandwidth of the pre-provided LSP is adjusted based on the network status.

At the border between the access and core networks, signaling and traffic aggregation need to be performed. Since the core network controls the aggregate level, the FSA signaling should be transparent in the core. Termination or proxy signaling mode is used to terminate or aggregate the FSA signaling at the edge of the core network.

V. Conclusion

Many control schemes have been proposed for flow-level traffic control. However, flow-level control is applied only in limited areas such as flow monitoring and traffic control at edge nodes. No clear solution for end-to-end control has been proposed. Scalability and the lack of a business model are the major problems in providing end-to-end flow-level control.

This paper proposed a network architecture to resolve these problems. The independence of transport and service functions is necessary for developing a viable business model. Our architecture design is based on separate transport and service strata. Both dynamic QoS control and provision-based QoS control are possible in the same framework. The notion of independence of service and transport functions has been widely discussed. However, previous studies have focused on controlling edge nodes. This paper introduces FSA technology as a key element. Specifically, proxy FSA function in the first edge node is proposed to combine the control of transit nodes with policy-based control at the edge. Transit nodes can be configured dynamically by FSA signaling triggered by the first edge node. Having an FSA proxy feature at the edge node, various types of CPE can be supported.

For the scalability and functionality, the control mechanisms of the core and access networks were designed independently. The core and access networks can be independently upgraded; therefore, the architecture can be applied to future convergence control of fixed and mobile networks without fundamental architectural change. The access network focuses on dynamic QoS control at the flow-level, and the core network focuses on the reliability of the network. The implementation complexity of the control procedure is reduced. In the core network, the complexity of call-by-call control is removed by using monitoring capability. In the access network, the complexity of in-band signaling is reduced by combining it with the RACF.

We have identified several future research issues.

First, MPLS technology has been proposed for aggregate flow control. Aggregate FSA could be a good candidate to replace MPLS. The FSA technology can remove the over provisioning concept in the core network with its dynamic resource allocation of aggregate flow. For aggregate FSA, further research needs to be done, especially in the areas of reliability and monitoring capability. The release 2 FSA activities will be extended in this direction.

For AR and VR service under current FSA requirements, the response of in-band signaling is required to obtain the network available resource. Combining AR with out-of-band signaling is being carefully examined because AR cannot be implemented without response. One possible alternative to out-of-band AR could be to assign the available network rate based

on the fair share of the available rate in the local node. A performance study needs to be undertaken in this area.

A flexible and scalable network architecture is necessary to accommodate the diverse future information and communication technology services. New services such as IP-TV and mobile multimedia are gaining more attention. Further investigation needs to be done in the areas of seamless mobility, flow-level resource control in the multicast environment, personalized advertisement, and security.

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Jongtae Song is a senior research staff member of ETRI, Korea. He received his BS degree in electronics and electrical engineering from the Korea Advanced Institute of Science and Technology (KAIST) in 1990, his MS degree in electrical engineering from the University of Southern California in 1994, and his PhD degree in electrical engineering from Polytechnic University, Brooklyn, in 1998. He worked for Bell Labs Lucent Technologies from 1998 to 2001 and for several startup companies (including Core Networks and Parama Networks) in New Jersey from 2001 to 2004. Since he joined ETRI in 2004, his work has been focused on BcN network architecture, QoS control, and flow-based network control architecture.



Soon Seok Lee received his BS, MS and Ph.D degrees in industrial engineering from Sungkyunkwan University, Korea, in 1988, 1990, and 1993, respectively. In 1993, he joined ETRI, where he has worked on high-level design and planning of networks, including ATM, mobile, and optical networks. In 2003, he was the chief architect for optical Internet with the Network Technology Lab, ETRI, where he is a principal member of engineering staff. He is a project leader for BcN network engineering and high-level network control platform design. His research interests include converged network architecture, optical Internet, optical networking, network planning and design, and network performance engineering.



Kug-Chang Kang is a senior member of the BcN Architecture Team of ETRI, Korea. He received his MS and PhD degrees from Seoul National University, Korea in 1992 and 1997 respectively. In 1997, he joined ETRI and has participated in many research projects in the areas of network system engineering, QoS/TE management, network evolution, service management, and network planning. He is involved mainly in network architecture design. His research interests include networking and service architecture, QoS/SLA architecture, personalization, and identity management.



Noik Park is a senior member of the BcN Architecture Team of ETRI, Korea. He received his MS and PhD degrees from the Sungkyunkwan University, Korea in 1995 and 2000 respectively. In 2000, he joined ETRI and has participated in many research projects in the areas of network system engineering, QoS/TE management, network evolution, service management, unified AAA architecture, and so on. Currently, he is involved mainly in the design of BcN architecture. His research interests include next generation networking and service architecture, network evolution strategy, AAA architecture, traffic engineering, and IP-mobility architecture.



Heuk Park received the PhD degree in physics in 1995 from Seoul National University, Seoul, Korea. He joined ETRI in 1995, where he has been involved in research on optical packet communication and optical transmission systems. Currently he is researching network architecture for future communication.



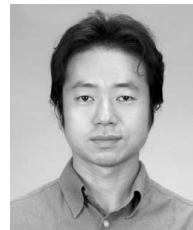
Sunghyun Yoon received the BS and MS degrees in computer science from Chungbuk National University, Cheongju, in 1998 and 2000 respectively. In 2000, he joined ETRI, Daejeon, Korea, where he is currently a senior member of engineering staff. His research interests are in BcN and Mobile IPTV.



Kyung Gyu Chun received the BS and MS degrees in electronics engineering from Kyungpook National University, taegu, in 1982 and 1984. He received the PhD degree in electronics engineering from Chungnam National University, Daejeon, in 2003. In 1984, he joined ETRI, Korea, where he is currently a principal member of engineering staff. His research interests are in MPLS and Ethernet and optical transmission systems.



Mi Young Chang received her BS degree in economics from Seoul Women's University, Korea, in 2002. She received her MS degree in business from Hanyang University, Korea, in 2004. Her research interests include telecommunications management, information communication technology (ICT) strategy, Internet industry analysis, business models, and knowledge management.



Jinoo Joung received his BS degree in electronics and electrical engineering from Korea Advanced Institute of Science and Technology in 1992. He received his MS and PhD degrees in electrical engineering from Polytechnic University, Brooklyn, New York, in 1994 and 1997, respectively. He worked for Samsung Electronics from 1997 to 2005. In 2005, he joined the Department of Computer Science of Sangmyung University, Seoul, Korea. His research interests include network architecture, QoS control, and various embedded network system designs and implementations.



Young Sun Kim is the director of the Network Research Group of ETRI, Korea. He received the MS and PhD degrees from Korea University, Korea, in 1991 and 1982, respectively. In 1982, he joined ETRI and has participated in many research and development projects in the areas of telecommunication network planning, SLA routers, BcN network planning, next generation OSS and so on. He was formerly director of the Internet Technology Research Group, the Router System Research Group, and the BcN Service Research Group. He is currently a principal member of engineering staff. His research interests include BcN networking and service architecture, SLA architecture, and Next generation OSS.