End-To-End QoS Control Architecture and Route Selection Method for IP Networks

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In this paper, we propose a new end-to-end QoS control architecture and an optimum core route-selection method that simultaneously considers both the access and core networks' status. The proposed method makes it possible to provide end-to-end QoS-guaranteed services for dual-mode mobile terminals that can use multiple access networks simultaneously, with efficient use of network resources. Simulation results show that our method improves the number of accepted requests for bandwidth guarantee in comparison with the existing methods. We also implemented a prototype QoS control system and confirmed that our proposed method worked well. The processing time of the prototype is within a few seconds for each QoS request.

1. Introduction

In the emerging ubiquitous network environment, the IP-based core network connects with a wide variety of wireless access networks to provide ubiquitous access to end users. It is expected that many people will use multiple network services with portable communication terminals that support several kinds of access technologies and mobility. Some of the applications, especially real-time applications, always require QoS guarantee, and end users may require QoS guarantee when the best-effort quality is unacceptable. Therefore, we believe it is important to provide end-to-end QoS as demanded by users and applications and to continuously provide QoS guarantee when users are moving. To achieve end-to-end QoS guarantee, network resources should be allocated along the data path, including the access network and core network. Even if an access network with sufficient resources can be selected for a flow, end-to-end QoS guarantee is not possible if the core network route is congested. Conversely, even if an optimum route with adequate resources can be prepared for a flow, communication quality will be degraded if there is access network congestion. Therefore, we need a route selection mechanism that comprehensively considers the status of the access network and the core network.

In this paper, we propose a new QoS control architecture in which the optimum pair of access network and route in the core network is selected for each communication flow that requires QoS guarantee. We calculate the access cost and core cost based on, respectively, the status of the access network and the status of the core route and then select the route having the minimum total cost. This architecture is based on 1) the combination of an access network selection technology and core route selection technology we have already proposed, 2) a routing control technique that enables the provision of QoS-guaranteed service with efficient core network resource usage,[1)] and 3) an access network selection technique called application-oriented routing and mobility (AoRM)[2)] that considers the access network status and application requirements.

Section 2 of this paper describes the proposed architecture. Section 3 describes a new route selection algorithm that we propose. Sections 4 and 5 describe an evaluation and the implementation of this algorithm. Section 6 describes a prototype system for achieving the QoS control architecture described in Section 2, and Section 6 concludes the paper.

2. Architecture overview

2.1 Requirements

To achieve end-to-end QoS-guaranteed communication, packets should be transmitted along a route that has sufficient resources. Therefore, the key issue is how to correct information such as which access networks the end terminal can access, which core routes can be selected, and the conditions of these access networks and core routes. Using this information, admission control can be done and the data path can be determined. Of course, to accept as many requests as possible when the route is determined, not only the availability of network resources but also the efficiency at which they can be used should be considered. Once QoS-guaranteed communication starts, the QoS-guaranteed service should be provided continuously, even if the terminal is moving. The main requirements for an end-to-end QoS control architecture are as follows:

1) Dynamic network information correction.
- Admission control should be done according to the end-to-end network conditions when the request occurs.
- Route selection should be done for each flow that requires QoS guarantee so that both the access network and core network resources are used efficiently.

2) Route control.

The guaranteed flow packets should be transmitted along the determined route.

3) Detection of end terminal movement.

QoS control should be done when users who receive QoS-guaranteed service move.

To meet these requirements, several points need to be considered. The QoS control function should update the appropriate information to avoid an excessive load, which decreases the possibility for call-by-call QoS control. Mobility information such as a terminal's address and its new location should be related with QoS-guaranteed session information such as the route and allocated network resources when the terminal moves during QoS-guaranteed communication. This is because the resources allocated for the old route of the session should be released instead of allocating new resources for the new route. The most important point is how to increase the number of acceptable services using the limited network resources. In the remainder of this section, we propose a new architecture that takes these points into account. Although there are several points about function deployment and transaction overhead that need to be studied, we will leave them for future work. Instead, we focused on a route selection algorithm that achieves end-to-end QoS guarantee with efficient resource usage (described in Section 4).

2.2 Proposed architecture

We propose an optimum route selection method that considers the status of both the access and core networks and provides mobile nodes (MNs) with on-demand QoS-guaranteed services using the optimum route. This method is based on the combination of AoRM and a core network routing control technique.

Figure 1 shows the proposed architecture. It is assumed that multiple networks are available for MNs and the core network supports an MPLS traffic engineering (TE) function[3] and DiffServ over MPLS[4] to achieve route control and priority queuing control. The key functions are as follows:

1) Network management functions:

The mobility management (MM) server manages MN locations in the same way that home agents (HAs) manage MN locations in Mobile IP.[5]

It manages the MNs' available IP addresses and transmits packets for each MN session using appropriate IP addresses notified by the MNs.

- The QoS admission control (QA) server handles QoS signaling messages. When it receives a QoS request message, admission control and route control are executed by requesting the core resource management agent (CORMA). That is, the QA server does the following:
  ① Determines the section candidates (i.e., pair of edge routers) for the core network route and required QoS parameters such as the bandwidth and communication direction from the QoS request message.
  ② Sends this information to the CORMA as a resource request.
  ③ Receives an answer indicating whether the resources are available and the route costs for each candidate.
  ④ Selects the optimum access network and core network route.

  Then, the QA server sends a QoS reply message to the MN. All session information, for example, the MN's IP address, required QoS parameters, and determined route, are maintained at the QA server.
- CORMA manages the label switched path (LSP) resource information of each section according to the QoS class. When the CORMA receives a resource request from the QA server, it indicates whether there is sufficient bandwidth. If the bandwidth is sufficient, the CORMA assigns resources for the request and tells the QA server the cost of each requested section. After route determination at the QA server, the resources of the non-selected section are quickly released. If the available bandwidth falls below the threshold, the CORMA requests the optimum route/resource allocation (ORRA) server for more resources.

The ORRA server has a routing function that determines the optimum route for the LSP of each section according to the total amount of resources that are required. The ORRA server sets multi-

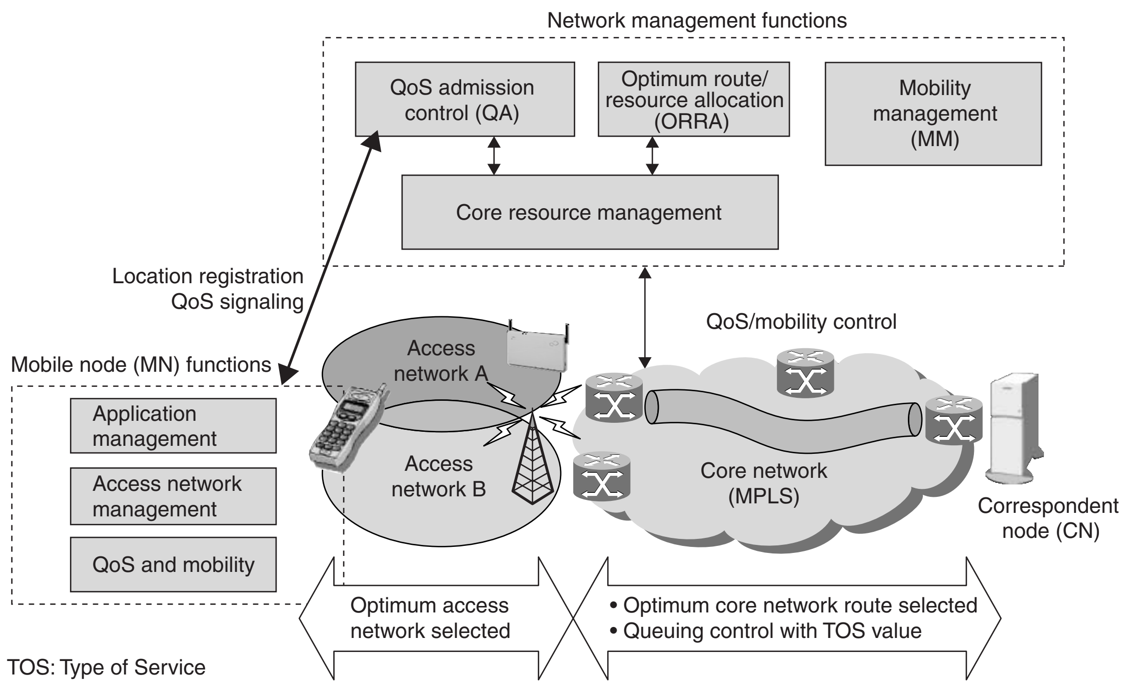

Figure 1
Proposed architecture.

ple paths for a given section between edge routers if it decides the multiple paths will provide better load balancing than a single path.

2) Mobile node functions:

- The application management function not only manages the application requirements and status but also monitors the fixed and variable port numbers used for identifying application data.
- The access network management function dynamically monitors network connectivity as well as the available bandwidth, transmission delay, and error rate of connected access networks.
- The QoS and mobility function generates QoS signaling messages when a session starts, and when the MN moves during QoS-guaranteed communication, it routes each data packet according to instructions in a QoS reply message and sends the information to the MM.

3. Route selection algorithm

Next, we explain the algorithm for optimum access network and core network route selection.

The basic idea is to set a cost value for each core network link and each access network according to its status, which is basically its load.

We calculate the cost of a link based on its non-reserved bandwidth while taking load balancing into consideration. We then select the route having the maximum available bandwidth. We define the cost of the link between node i and j as:

$$link\_cost(i, j) = 1/(R\_MAX_{ij} - R_{ij}), \qquad (1)$$

where R_MAX is the maximum reservable bandwidth and R is the reserved bandwidth at the link. Next, we determine the cost of an access network to represent its status. Because access networks have different characteristics, we must consider several elements to represent the access network conditions. These elements are 1) whether the available bandwidth is sufficient for the request; 2) the delay between the MN and access router (a long delay means congestion at the access point or a transmission error); and 3) the errors that occur due to the distance between the MN and access point, weak radio signals, and radio interference. Compared with the core network characteristics, the error rate and delay of the access network cannot be ignored. Therefore, we can define the cost of an access network a as:

$$access\_cost(a) = \frac{BW_{req}}{R\_MAX_a - R_a} \times C_{BW} + \frac{D_a}{D_{req}} \times C_D + \frac{E_a}{E_{req}} \times C_E , \qquad (2)$$

where BW_{req}, D_{req}, and E_{req} are, respectively, the required bandwidth, admittable delay, and admittable error rate of the request and R_MAX_a, R_a, D_a, and E_a are, respectively, the maximum reservable bandwidth, reserved bandwidth, current delay, and current error rate at access network a. C_{BW}, C_D, and C_E are constants that weight each term. When communication quality is seriously affected by the error rate, C_E should be bigger than the other constants.

After determining the cost of each link and access network, we select the route whose core network route cost plus access network cost is minimum. For each candidate access network a, we calculate the minimum-cost core network route from the edge node connected to the requested service server to the edge node connected to the access network using the Dijkstra algorithm. Let t be the minimum-cost core network route. Then:

$$total\_cost(a, t) = access\_cost(a) + \sum_{(i,j)\in t} link\_cost(i, j). \qquad (3)$$

We then select the set of access network a and core network route t whose $total\_cost(a,t)$ is minimum. This enables both access and core network load balancing.

4. Algorithm evaluation

4.1 Simulation model

We evaluated the effects of the proposed method in a simulation using the network model shown in **Figure 2**. In the model, two kinds of access networks connect to the core network, which has 16 nodes. Four of the edge nodes were prepared for server connections that we call server edge connections. The bandwidths of the links were as follows: 2.4 Gb/s between the core network routers, 2.4 Gb/s between the server edge and core network routers, and 1 Gb/s in the other links. The capacity of the access network was 1 Gb/s. Depending on the location, MNs can connect to access NW-A only or to access NW-A and B. The location of the MN was selected randomly. The arrival interval of requests and the holding time were distributed exponentially. The average holding time was 600 s, and we changed the arrival rate of requests according to the traffic intensity of the offered load. The requested bandwidth was 5 Mb/s. For simplification, we calculated the cost using the available bandwidth to choose the access network and core network route; that is, $C_D = C_E = 0$ in Equation (2). We used $C_{BW} = 0.2$ throughout the simulation.

4.2 Simulation results

Figure 3 shows the simulated request blocking rate as a function of traffic intensity, which is defined as the average holding time divided by the average arrival interval.

For reference, Case 1 shows the result when the MN has an interface that can only connect to access NW-A. Case 2 shows the result when only the optimum access network is selected, without considering the core network resources. In this case, no control was performed for the core network; that is, the shortest path was selected as the core network route. Case 3 shows the results for our proposed method. During this simulation, for all cases, the bandwidth of several links in the core network or several access networks was occasionally exhausted. As a result, Case 3 shows the best performance. This is because our proposal could select an end-to-end route by considering not only the access network condition but also the core network condition; that

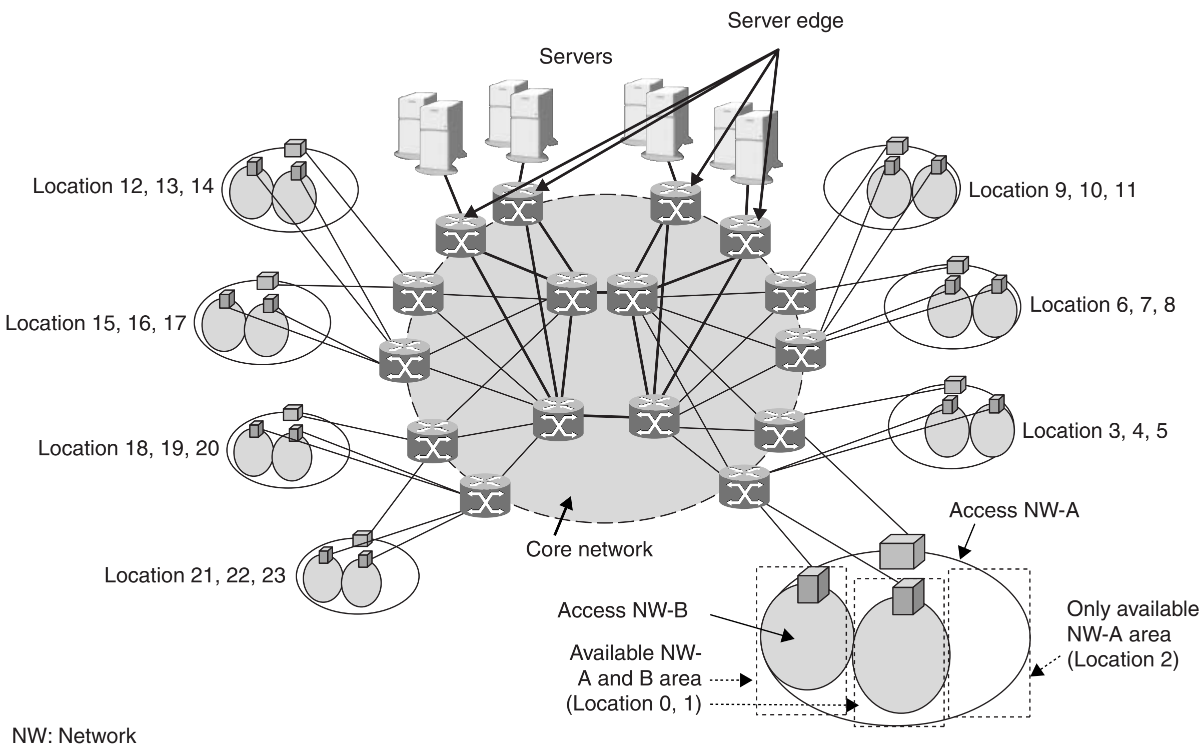

Figure 2
Network model.

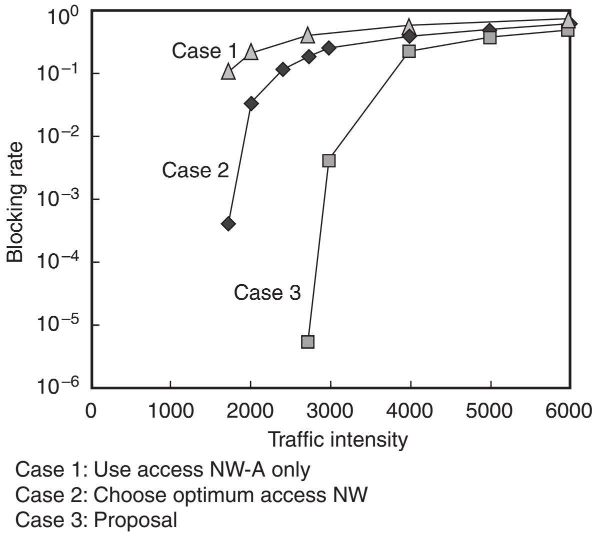

Figure 3
Simulation results.

is, it could select a route that avoided access network congestion and also congestion points in the core network. On the other hand, in Case 2, a route was selected by considering only the access network condition, and as a result, core network congestion was not avoided. Our proposed route selection method, therefore, makes it possible to reduce the service blocking rate when congestion occurs in both the access and core network because it enables dynamic selection of a route that avoids both access and core congestion points. The number of access networks and their capacity are expected to increase, so large amounts of traffic will be injected into the core network. Also, the traffic pattern is expected to change so often that it will become difficult to predict congestion points. Therefore, because our method increases communication capacity, it will be suitable for networks of the near future.

5. Implementation

5.1 QoS signaling style

We developed a prototype system to achieve the QoS control architecture described in Section 2. The most important consideration of our implementation was QoS signaling between MNs and the QA server because we have already implemented basic functions for access network control and core network control.[1),2)] The "Next Steps In Signaling" working group (NSIS WG) of the IETF is discussing a general signaling protocol. The NSIS WG has documented a signaling framework,[6)] and we considered that a path-decoupled signaling was suitable for our architecture. We think that path-decoupled signaling has various advantages for achieving end-to-end QoS in a large-scale network (**Table 1**).

5.2 Key features of our QoS signaling protocol

The key features of our QoS signaling protocol are as follows:

1) Access network status information can be included in the QoS request. Currently, if an MN can connect to two access networks, a QoS request from the MN contains two IP addresses and the costs of these access networks. This information enables the QA server to select the optimum access network and core network route pair.
2) QoS reply messages indicate the appropriate QoS parameters and access network to be used. In our implementation, a Type of Service (TOS) value and the IP address of a selected access network are set in the reply OK message. An MN can then communicate over a QoS-guaranteed route using the indicated IP address and TOS value.
3) At handover, a QoS request is re-sent to CORMA to reserve resources for a new route and release the old route's resources. When the QA server receives a QoS request with an existing session ID, it recognizes handover in the session and executes the appropriate control.

When multiple management domains exist along the communication route, each domain should have a QA server that supports QoS signaling to provide end-to-end QoS. Although we consider only one management domain in this implementation, we think the signaling protocol

Table 1
Advantages of path-decoupled signaling.

	Path-decoupled QoS signaling	Path-coupled QoS signaling
Description	Signaling message is exchanged between appropriate nodes (i.e., QA servers) for QoS guarantee.	Signaling message is exchanged between nodes on communication route to perform QoS setting at each node.
Requirement for routers	Not severe • Not necessary to support QoS signaling.	Severe • For complete QoS guarantee, all routers on route must support QoS signaling.
Scalability	Good • The QA server load can be reduced using multiple hardware resources. • The QA server can control routers for aggregated flow unit.	Not good • In a large-scale network, each router must retain a vast amount of information.
Mobility treatment	Quick • Because the QA server knows both the old route and new route information when it receives a new QoS request message, it is easy to quickly release network resources on the old path.	Slow • Difficult to quickly release network resources on old path when MN moves.

can also be used for multi-domain end-to-end QoS after a small expansion.

5.3 QoS signaling sequence

Figure 4 shows the basic QoS request procedure when the requester is an MN and the correspondent node is a fixed terminal. The procedure is as follows:

1) The MN sends a QoS request message to the QA server with information about the requirements of the application, candidates of access networks that the MN can use (e.g., CoA of Mobile IP), and their status. Although this message can be issued by the application server that manages session information such as the Session Initiation Protocol (SIP) server, we choose the MN as the QoS request initiator in this case because it knows both the session and access network information.
2) The QA server sends a reserve message to the correspondent node (CN) in order to confirm the QoS request. If the CN does not want to communicate with the MN with guaranteed QoS, the response message is "Not OK."
3) The QA server asks the CORMA if there are routes (i.e., LSPs) with available resources in the core network. Then, the QA server selects an optimum pair of access network and LSP based on the access network status described in the request message and core resource information provided by the CORMA.
4) The QA server sends a response message to the MN indicating the result of the request. If the result is "OK," the message includes information about the selected access network (e.g., selected CoA) and the value that must marked on the packet of the flow to identify the QoS class (e.g., the TOS value in the IP header). This value is used for queuing and route control in the core network.
5) The MN registers the relation between the application session and the selected access network to the MM so that downward packets can use the selected access network. Mobile IP can be used for mobility management.
6) The MN and CN apply the indicated TOS value to the packet header for core network QoS control. The MN uses the IP address indicated by the QA server so that upward packets can use the selected access network. Note that the functions mentioned above can

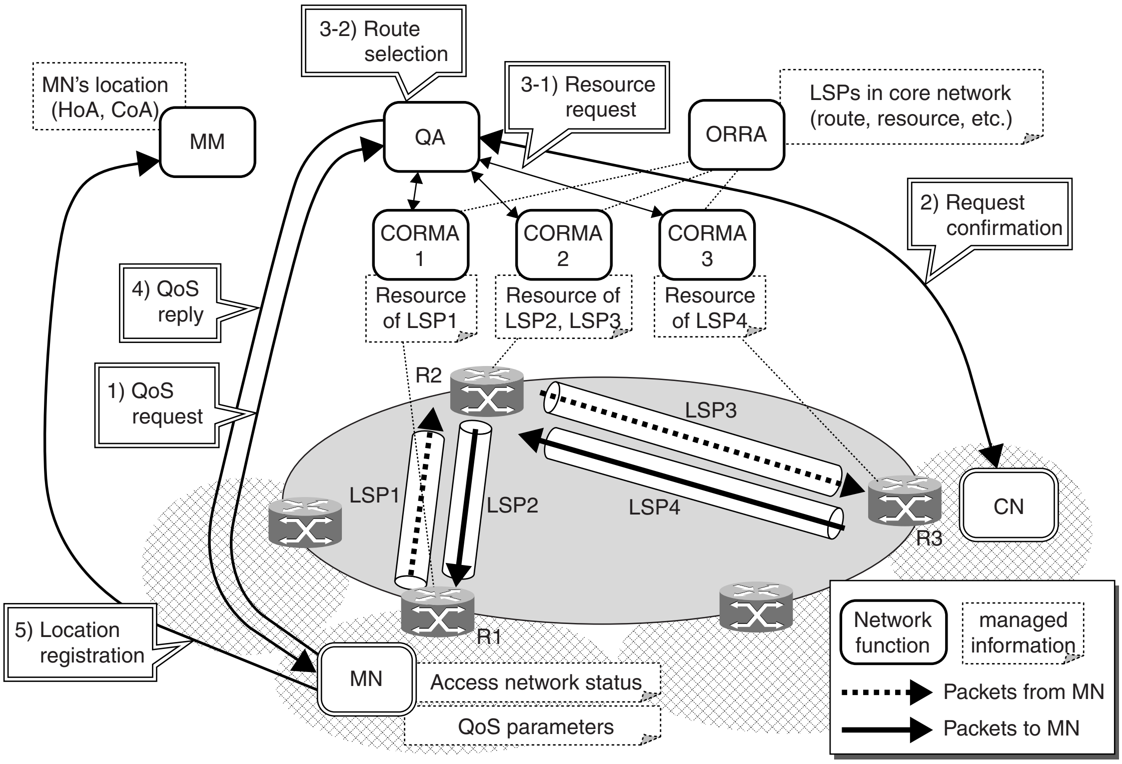

Figure 4
Basic QoS request procedure.

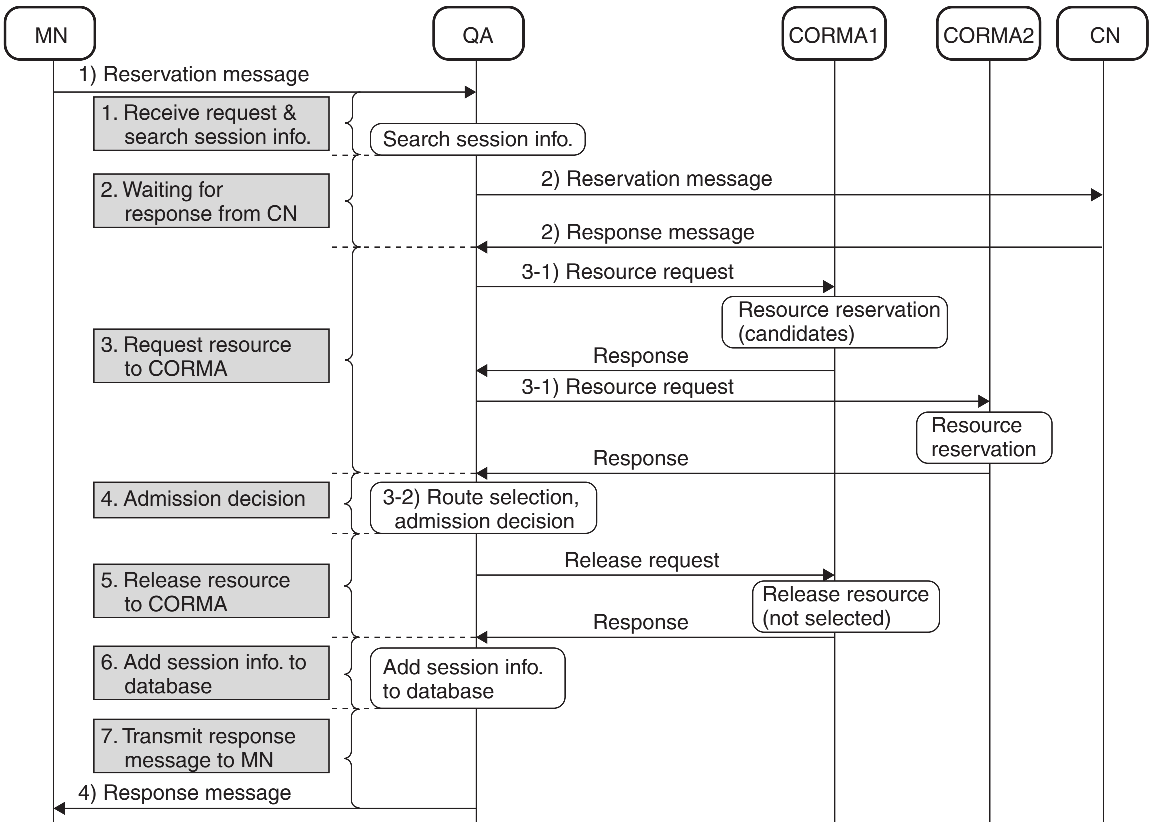

Figure 5
QoS reservation signaling sequence.

also be deployed in a different configuration.

Figure 5 shows the QoS reservation signaling sequence. The message format used in the sequence is based on the NSIS protocol.

6. Experimental verification

6.1 Experiment conditions

We have developed a prototype system that includes the QoS signaling protocol described above and verified it using the network shown in **Figure 6**. The access networks used were a WLAN and an emulated 4G cellular network. The R-factor of a video conference audio session was observed when congestion and a resource shortage for QoS guarantee occured in the core network. The congestion scenarios are shown in **Table 2**. The video bit rate and frame rate were 314 kb/s and 20 frames per second (fps), respectively, and the audio bit rate and codec were 64 kb/s and G711 u_law, respectively. To generate congestion in the core network, a constant-rate best effort (BE) traffic was injected by a traffic generator. The default route was Correspondent node-Router1-Router2-WLAN-MN.

6.2 Experiment results

The experiment results are shown in **Table 3**. Based on this experiment, our signaling protocol and QoS control architecture work well.

In Scenario 1, a performance degradation was avoided by core network QoS control because the traffic was guaranteed in the core network, even when the route passed through the congested point. On the other hand, core network conges-

Table 2
Congestion scenarios.

Scenario	Description
Scenario 1	Links from R1 (Router1) to R2 and from R2 to R3 are congested by best-effort traffic
Scenario 2	Links from R1 to R2 and from R2 to R3 are congested by best-effort traffic and are also short of bandwidth for QoS-guaranteed traffic

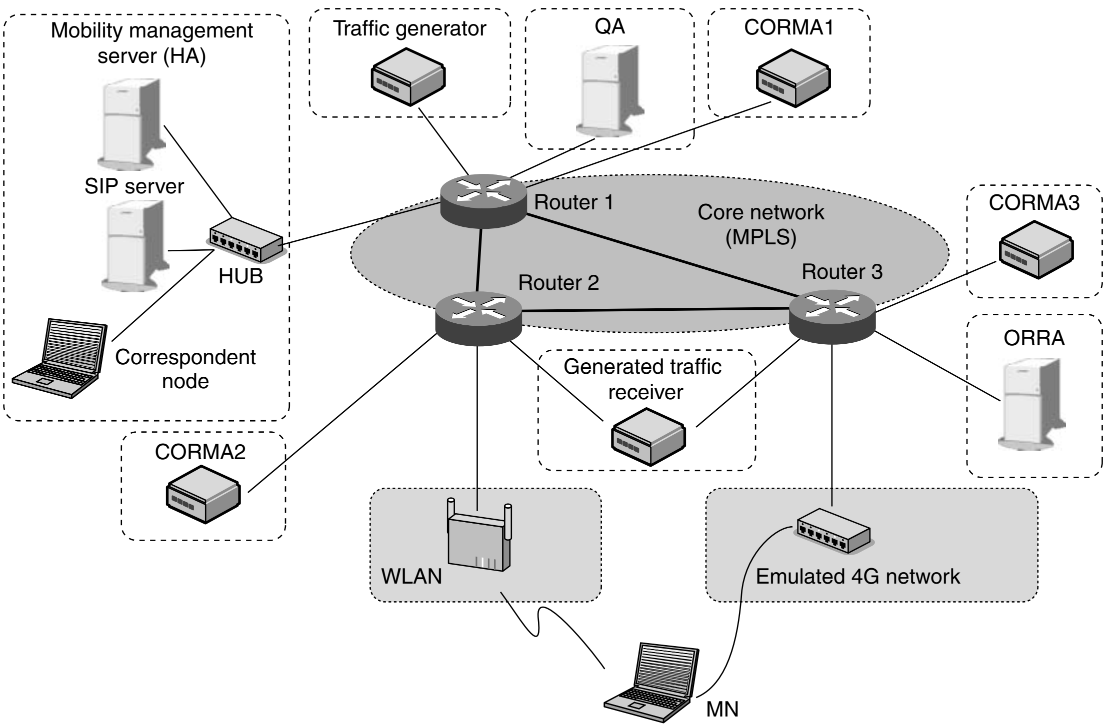

Figure 6
Experimental network.

tion could not be avoided simply by access network selection control. In Scenario 2, only the proposed route selection method showed good performance. In this scenario, the core network QoS control could not select the 4G access network route because it could not obtain alternative access network information. Our proposed method worked well and showed good performance in both scenarios. The observed R-factors as a function of link utilization at the congested point are shown in **Figure 7**. With our proposed method, a satisfactory R-factor of over 90 was achieved during congestion.

6.3 QoS signaling process

Figure 8 shows the signaling processing times in ms for new QoS reservations at the QA server for an upstream QoS request session (left), downstream QoS request session (middle), and bi-directional QoS request session (right).

As the figure shows, the processing time for a new QoS reservation in the QA server is slightly less than 1 s for a unidirectional reservation and about 1.6 s for a bidirectional reservation. A bidirectional reservation takes longer than a unidirectional reservation because 1) it requires twice as much processing to obtain resources and 2) the QA server has to register much more session information in the database than in a unidirectional reservation. Also, 90% (from about 700 to 1500 ms) of the processing time was for database transactions for registration. The log of the CORMA indicated that the CORMA quickly processed resource reservations in from 6 to 14 ms. This is because the CORMA had to maintain less information than the QA server and because the CORMA kept this information in its own memory instead of a database. The transmission delay of messages is about 1 ms in this experimental local network. We think the signaling message should be handled with high priority so the network transmission delay is limited to only several ms.

Table 3
Experiment results.

Scenario	Control method		
	Access NW selection only	Core NW QoS control only	Proposal
Scenario 1	Bad with route R1-R2-WLAN (BE)	Good with route R1-R2-WLAN (QoS)	Good with route R1-R2-WLAN (QoS)
Scenario 2	Bad with route R1-R2-WLAN (BE)	Bad with route R1-R2-WLAN (BE)	Good with route R1-R3-4G (QoS)

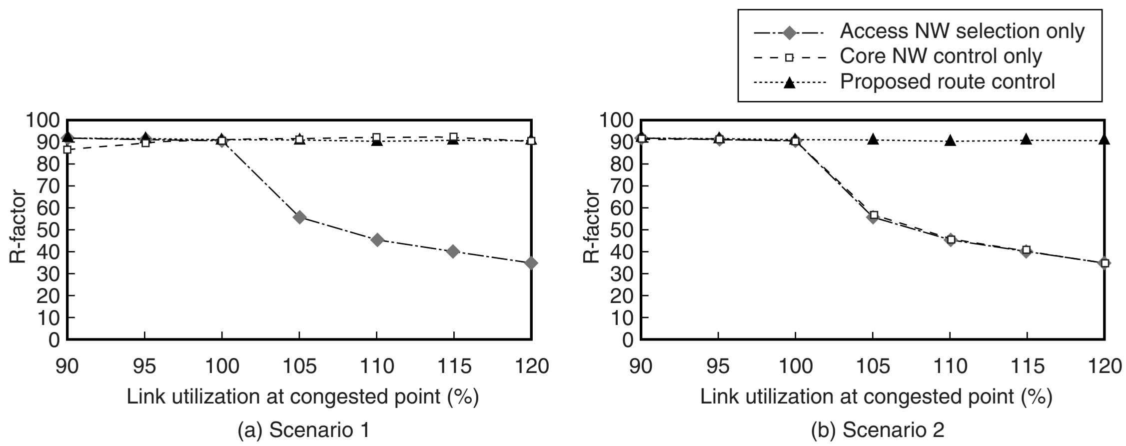

Figure 7
Observed R-factor.

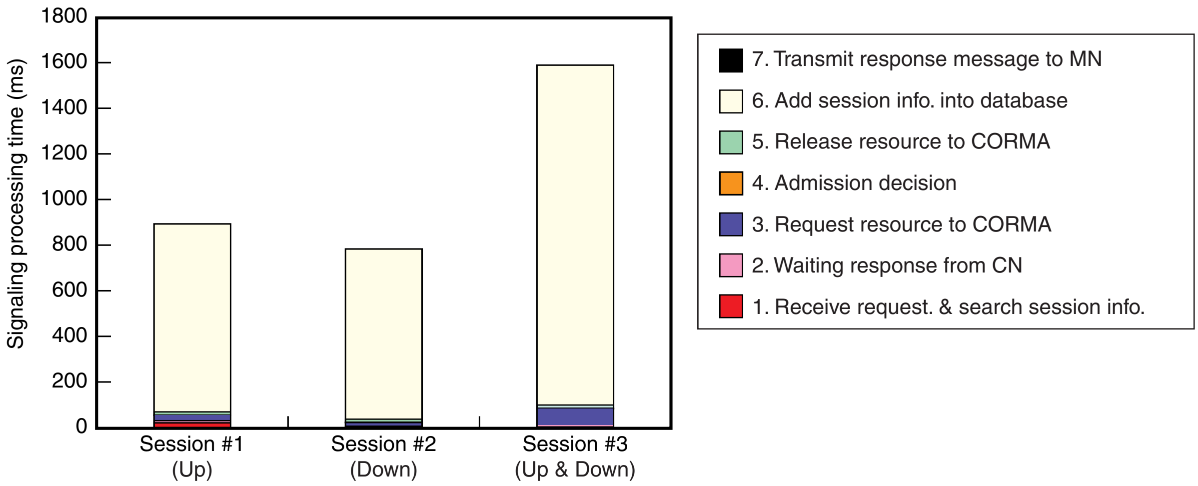

Figure 8
QoS signaling processing time.

7. Conclusion

In this paper, we proposed a new end-to-end QoS control architecture and optimum route selection method. Simulations showed that our route selection algorithm increased the capacity of QoS-guaranteed communication service, dynamically avoiding congestion in the access network and core network. A prototype system showed that our QoS signaling protocol achieved the intended route selection so that quality of communication can be maintained and that the QoS signaling processing time is about several 100 ms for unidirectional reservation. The NGN standardization group of the ITU-T is now discussing end-to-end QoS architectures and their mobility requirements. Our QoS control architecture and route selection method can be a solution for realizing QoS services.

Acknowledgement

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