Scalable Quasi-Dynamic-Provisioning-Based Admission Control Mechanism in Differentiated Service Networks

Woo-Seop Rhee, Jun-Hwa Lee, Jae-Hoon Yu, and Sang-Ha Kim

The architecture in a differentiated services (DiffServ) network is based on a simple model that applies a per-class service in the core node of the network. However, because the network behavior is simple, the network structure and provisioning is complicated. If a service provider wants dynamic provisioning or a better bandwidth guarantee, the differentiated services network must use a signaling protocol with QoS parameters or an admission control method. Unfortunately, these methods increase the complexity. To overcome the problems with complexity, we investigated scalable dynamic provisioning for admission control in DiffServ networks. We propose a new scalable qDPM² mechanism based on a centralized bandwidth broker and distributed measurement-based admission control and movable boundary bandwidth management to support heterogeneous QoS requirements in DiffServ networks.

Keywords: Dynamic provisioning, bandwidth broker, measurement-based admission control (MBAC), movable boundary, DiffServ.

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I. Introduction

Current IP networks provide only simple data transmission service, such as best-effort traffic, which is identified only by the service class using the price or connection type (dial-up or leased line). There is no guarantee to the user of quality of service requirements, not even delivery of data. This best-effort service stems from a clear design policy to trade everything possible for simplicity. Because the major applications that first used the network could cope with a wide range of services, the network's simplicity allowed wide deployment of the technology [1]. However, due to the recent development of transmission technology, broadband Internet is constructed by xDSL and Metro Ethernet technologies. Moreover, IP networks must provide new differentiated service applications, such as Internet broadcasting, VoIP, VPN, etc., according to the development of various Internet multimedia content. These service applications may require stringent quality of service requirements in terms of bandwidth, latency, and other data transfer parameters. To satisfy these service requirements, the following quality of service technologies need to be guaranteed in future IP networks.

- Admission control
- Congestion control
- Traffic conditioning
  - Traffic Shaping
  - Metering
  - Marking
  - Dropping

• Priority and Scheduling

Among these QoS technologies, admission control should take preference. The purpose of admission control is to allocate the network resources for bandwidth provisioning so that the network has an upper bound of packet loss probability and delay variation through a reliable connection.

Using these guaranteed QoS technologies, researchers have studied Internet networks as the combined architecture of an integrated service network (IntServ) and a differentiated service (DiffServ) network proposed by IETF (Fig. 1).

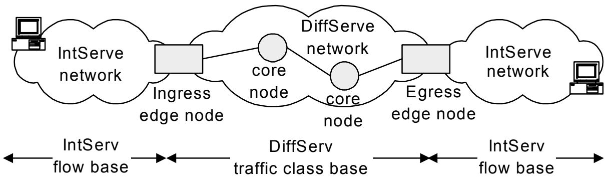


Fig. 1. Internet network architecture.

An IntServ network has three service classes based on delay requirements: guaranteed-service, controlled-load service, and best-effort service [2]. The guaranteed-service class and controlled-load service class need a reservation of network resources through signaling, such as RSVP to guarantee each flow's QoS requirements. Although this kind of resource reservation can satisfy per-flow QoS requirements, it needs a huge storage to contain the information on the state of the network of each flow. This creates a scalability problem in large IP networks.

On the other hand, a DiffServ network is based on a simple model in which the traffic entering a network is classified and conditioned at the boundary edge node and then assigned to different behavior aggregates. These behaviors are defined as a per-hop behavior (PHB). There are three kinds of PHBs: expedited forwarding (EF) service, assured forwarding (AF) service, and best-effort (BE) service according to the differentiated service code point. All packets with the same code point are grouped together and handled the same way in the network [3]. These PHBs do not deploy to each flow but to the aggregated traffic in consideration of the scalability. For simplification of core node function and scalability, complicated functions, such as traffic identification, policing, etc., are distributed to the edge node and the core node can perform only the simple buffer management functions according to the service class for a QoS guarantee.

However, because the network behavior is simple, the network structure and provisioning are complicated. As the different destination's traffic is concentrated in one egress edge node and when the traffic and routing change dynamically, network congestion can occur. Therefore, network provisioning needs network topologies and more routing information. Static provisioning cannot cope with such a dynamic change in input traffic and network topology.

If an ISP wants dynamic provisioning or a better bandwidth guarantee, the DiffServ network must have a signaling protocol with QoS parameters or an admission control method. However, these methods increase the complexity. To overcome these problems of complexity, we investigated dynamic provisioning for admission control in the DiffServ network.

In this paper, we propose a new scalable quasi-dynamic provisioning with measurement-based admission control and movable boundary (qDPM^2) mechanism based on a centralized bandwidth broker and distributed measurement-based admission control and movable boundary bandwidth management to support heterogeneous QoS requirements in DiffServ networks.

The rest of the paper is organized as follows. Section II describes the admission control methods that apply to IP networks. In sections III and IV, we describe the algorithm and procedure of the proposed mechanism and present the simulation model and results for the performance evaluation. Finally, section V gives the conclusion.

II. Admission Control Mechanisms for IP Networks

There are two admission control methods in IP networks: distributed admission control and centralized admission control.

1. Distributed Admission Control

Distributed admission control performs admission control through signaling at each ingress edge node within the domain, for example, packet networks. There are two types: parameter-based admission control and measurement-based admission control.

Parameter-based admission control has been used in ATM and packet switching networks. When the user requests a connection establishment, this method performs the admission control function based on the requested traffic parameters (peak rate, mean rate, CDV, etc.) of signaling messages [4]. However, parameter-based admission control needs a huge amount of storage for the traffic parameters and status of all the setup connections in each node through the connection. If this method is deployed in a large IP network, there are fundamental limits to the scalability of such an admission control algorithm because the amount of state information and traffic parameters increase proportionally with the number of connections [5].

To solve the scalability problem, some researchers have investigated measurement-based admission control (MBAC). There are two types of MBAC: data packet MBAC and probing packet MBAC. These mechanisms can solve the scalability problem of the parameter-based admission control since the network does not need to maintain information on the network state for all traffic connections in each node along the path.

Data packet MBAC measures the actual traffic load at every time window and performs the admission control function using the estimation value based on the current measured traffic volume [6]. For this method, Jamin et al. evaluated three admission control algorithms of the data packet MBAC method—measured sum, acceptance region, and equivalent bandwidth—through simulation of several network scenarios based on the levels of delay and loss [7]. Floyd described the difficulties in estimating the average arrival rate from measurements [8]. Even if there were a steady-state average arrival rate, this average arrival rate would be difficult to determine from measurements because of the possible long-range dependence of the aggregate traffic. Therefore, traffic measurement is not always a good predictor of future behavior, and the measurement-based approach to admission control can lead to occasional packet losses or delays that exceed the requested QoS.

The probing packet MBAC performs the admission control using the probing packet and measures the network status to determine whether there are enough resources in the network to accept a new connection. This implies that the probing packet rate may be as large as the generated packet rate of the new connection. The role of the probing packet is to make a stress to the network as much as the packet transmission rate which the new connection will generate in its session packet transmission phase. The probing packet MBAC procedure is divided into the probing packet transmission phase and the session packet transmission phase. The sender transmits the probing packets at the peak rate of the session data rate in the probing packet transmission phase. Upon reception of the first probing packet, the receiver starts measuring the probing packet arrival statistics over the probing duration. At the end of the probing time, the receiver estimates whether there are enough resources available along the path to meet the user's QoS requirements by calculating the received probing packets. This measurement report is sent to the sender at a high priority transmission rate. Based on the measurement report, the sender accepts the requested connection if the calculated probing packet loss probability is below the threshold of the target loss probability and starts the session packet transmission phase.

Bianchi et al. first introduced approximate analytical models to evaluate the performance of MBAC [9]. They outlined an analytical model to evaluate the throughput performance of an MBAC scheme based on bandwidth measurements only. Their model is extremely accurate for networks loaded with a constant bit rate. However, as the number of accepted connections at time t does not uniquely identify the amount of bandwidth allocation over the link, their model cannot depict accurate behavior in a network with a variable bit rate.

Elek et al. introduced basic admission control procedures for probing-based MBAC [10]. They showed the relations between the data packet queue and the probing packet queue in a simulation. As the probing packets are transmitted with a lower priority than the session data packets in the node, the threshold of the loss probability of the probing packets can be defined as at most one order of magnitude higher than the user target loss probability.

2. Centralized Admission Control

Centralized admission control performs admission control in the bandwidth broker (BB). It makes the acceptance decision of the user-requested flow and performs network resource management and allocation. A BB is located in each DiffServ domain and performs service level agreements between a subscriber and the DiffServ network and between DiffServ networks [11], [12].

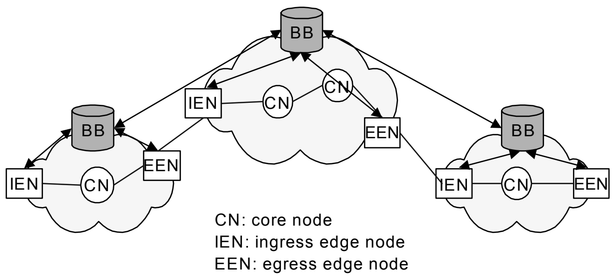


Fig. 2. Bandwidth broker in the DiffServ domain.

Network resource management in IP networks, so far, has used a simple static provisioning mechanism. Static provisioning allocates the network resources offline to a predefined routing path according to the service level agreement during some period (day, week, or month). When a user requests a new flow to the network, the bandwidth broker determines if it is acceptable on the basis of the statically allocated network resources. However, this mechanism cannot adapt to a network situation with dynamically changing traffic and routing. Even for single service traffic, it cannot prevent traffic overload. Furthermore, as the network resource allocation update is performed periodically, it is difficult to manage the network resources efficiently because of unexpected user traffic violations and congestion in the network state.

Meanwhile, dynamic provisioning properly allocates the network resources to the requested user flow according to the network situation. This means that such an algorithm has to provide fast reactions to unexpected traffic pattern changes. An efficient network resource management mechanism in a DiffServ network depends on how the ingress edge node can perform the distinct functions according to service classes instead of a simple operation in the core node. The traffic violation information of the network should be gathered immediately by the bandwidth broker and transmitted to each ingress edge node.

Liao and Campbell proposed a link-based dynamic core provisioning mechanism that maintains a core traffic load matrix [13], [14]. It has link bandwidth information and is periodically updated with the measured per-class link load. This mechanism can prevent congestion from transient violations. However, it must maintain a core traffic load matrix for each link, and whenever a new flow is requested, it must ask the bandwidth broker whether this new flow is acceptable. Additionally, with this method there must be a communication capacity between the bandwidth broker and each core node for the periodic report of link bandwidth information.

Zhang and Hou proposed a more efficient dynamic provisioning mechanism that provides a path-oriented and quota-based (PoQ) dynamic bandwidth allocation mechanism [15]-[17]. This mechanism divides admission control into path level and link level. The path level performs the admission control within an allocated quota in the under load. The link level performs link bandwidth management that allocates and de-allocates bandwidth on a per-flow basis. This means that although this mechanism uses a two-level approach, it still needs to maintain an accurate link state for each critically loaded link.

We have described the admission control methods that are applicable in IP networks. These methods have pros and cons according to their characteristics. Table 1 summarizes the pros and cons of each admission control method. The important points of an admission control method for IP networks are scalability and simplicity.

III. Quasi-Dynamic Provisioning Mechanism

The proposed qDPM^2 mechanism for admission control in a DiffServ network is divided into two phases: path-level admission control and link-level admission control. The bandwidth broker manages only the path-level bandwidth resources within the domain and path-level admission control is performed at the ingress edge node. For the link-level admission control, MBAC and the movable boundary are performed for management of the link-level bandwidth along the path. For the MBAC mechanism, we used the two-phase measurement-based admission control method proposed in [18]. Figure 3 depicts the operation model of the proposed mechanism.

The bandwidth broker calculates the path bandwidth within the domain and sends it to each ingress edge node. The ingress edge node then performs the path-level admission control using the path bandwidth. If the path bandwidth is fully occupied, the ingress edge node performs the movable boundary bandwidth management and extends the path bandwidth of the EF or AF service. It also performs the link-level admission control using MBAC. On the other hand, if congestion occurs in the core node along the path, a congestion notification is sent to each ingress edge node through the bandwidth broker. The ingress edge node then performs only link-level admission control using MBAC if there is enough path bandwidth.

Table 1. Classification of admission control methods.

	AC method		Pros	Cons	Ref.
Distributed AC	Parameter-based AC		- Exact admission control for real time service	- Scalability problem	[4]
	Measurement-based AC	Data packet MBAC	- Scalability	- Difficulty in measuring and estimating exact traffic	[6]-[8]
		Probing packet MBAC	- Scalability - Simple measurement and admission control	- Needs probing duration time	[9], [10]
Centralized AC	Static provisioning		- Simple admission control and management	- Congestion - Over-provisioning	[11], [12]
	Dynamic provisioning		- Congestion avoidance	- High complexity	[13]-[19]

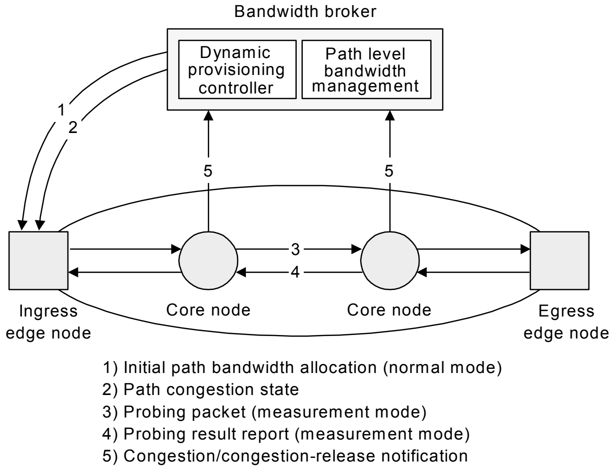


Fig. 3. The operation model for the proposed mechanism.

This mechanism simplifies the bandwidth data calculation in the bandwidth broker by performing only path-level resource management. It also has an advantage in that the ingress edge node can perform the admission control for itself within the path-level bandwidth regardless of any communication with the bandwidth broker. Additionally, when the path-level bandwidth allocated at the initial provisioning is fully occupied, the proposed mechanism performs movable boundary bandwidth management and MBAC to extend the allocated bandwidth at the edge node for the link-level admission control. Another advantage of the proposed mechanism is that the bandwidth broker need not maintain any link-level bandwidth information for the link-level admission control. We describe more detailed procedures in the following sections.

1. Path-Level Admission Control (Normal Mode)

The concept of the path is the same as that of the ATM VPC (Fig. 4). The path is the bundle of flows that traverse the same destination between the ingress edge node and egress edge node. The path dimensioning is performed by means of a routing protocol (OSPF or BGP) at the BB. For the path-level admission control, the bandwidth broker performs the initial path bandwidth provisioning that is allocated previously for each path.

In path-level admission control, if the path-level bandwidth is larger than the new requested flow bandwidth, the ingress edge node can decide immediately without help from the bandwidth broker.

The calculation of the initial path bandwidth provisioning is performed as follows:

1) Bandwidth partitioning according to the service class, EF/AF/BE, in each node. Partitioned bandwidth of each service class of node *i*, link *l* : $BW^{l}_{i,ef}$, $BW^{l}_{i,af}$, $BW^{l}_{i,be}$.
2) Path, $p(s,d)$, establishment from the ingress edge node to the egress edge node using a routing protocol: Number of paths going through link *l* node *i* = N^{l}_{i} , for $i, l \in p(s,d)$.
3) Bandwidth allocation according to the service class in each node along the path $p(s,d)$: Initial bandwidth for each service class ($BW^{p(s,d)}_{i,ef}$) = partitioned bandwidth of each service class ($BW^{l}_{i,ef}$)/number of paths (N^{l}_{i}).
4) Initial path-level bandwidth in an ingress edge node ($BW^{p(s,d)}_{ef}$) selects the minimum bandwidth among the initial bandwidth for each service class of each node along the path: $IBW^{p(s,d)}_{ef} = \min (BW^{p(s,d)}_{i,ef})$, for $i \in p(s,d)$
5) Procedures 3) and 4) are also performed for the initial path-level bandwidths of AF and BE services, $IBW^{p(s,d)}_{af}$ and $IBW^{p(s,d)}_{be}$.

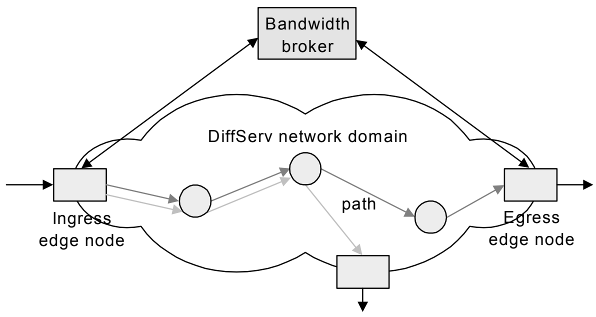


Fig. 4. The concept of the path in the BB domain.

2. Link-Level Admission Control (Measurement Mode)

If the path-level bandwidth is fully occupied, link-level admission control is performed in terms of MBAC and movable boundary bandwidth management for the admission control of MBAC.

The relationship between the target data loss and probing packet loss is that the probing packet loss probability (*PLpr*) is one order of magnitude higher than the target data loss probability (*TLpr*): $TLpr \le 10\ PLpr$. The reason is that the probing packet is serviced at a lower priority than the data packet in the priority scheduling. Elek et al. proved that in [10]. Therefore, if the measured probing packet loss probability is ($MPLpr$) $\le TLpr/10$, the MBAC can accept the requested flow [10], [18].

The link-level admission control flow can be explained as follows:

1) When the path-level bandwidth is fully occupied,

movable boundary bandwidth management is performed at the boundary of the edge node. It extends the pre-allocated EF and AF service bandwidth to the unused BE service bandwidth within the path bandwidth (Fig. 5). The amount of requested bandwidth can be extended. However, the minimum bandwidth of BE service must be maintained in the path bandwidth.

2) Probing packet-based MBAC is performed to check whether the extended bandwidth is available along the path. This measurement mode operation need not maintain any bandwidth information or status.
3) When the ingress edge node receives a congestion notification from the bandwidth broker, although some path-level bandwidth remains, the measurement mode is performed. The core node along the path triggers this congestion notification when the congestion is detected.

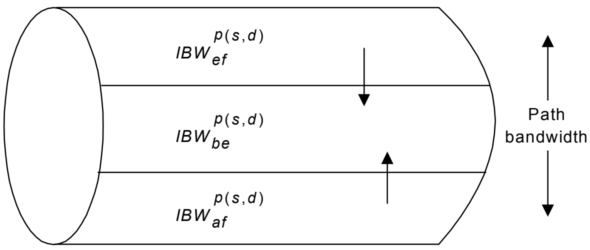


Fig. 5. Movable boundary bandwidth management scheme.

3. Scheduling Method for MBAC in the Core Node

To support the MBAC mechanism, each core node along the path performs queue scheduling as in Fig. 6. It has data and probing packet queues for each service class.

A core node performs scheduling for MBAC as follows:

1) The data packets of the admitted flow are inserted into the EF/AF data queue. These data packet queues are served at a higher priority than the probing packet queues. However, the capacity limit for the data packets cannot be exceeded and may be provided by means of the non-work conserving scheduling.
2) The probing packets of MBAC are inserted into the EF/AF probing queue. The probing packet uses only available bandwidth within the allocated bandwidth for the EF/AF service class without affecting established session flows.
3) When the EF/AF data queue length is over the threshold, the core node sends a congestion notification to the bandwidth broker.
4) When the usage of each service bandwidth is under the threshold, the core node reports a congestion release to the bandwidth broker.

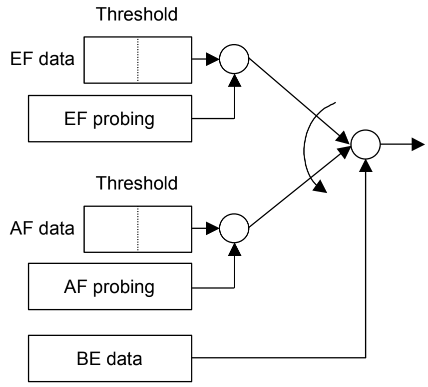


Fig. 6. Scheduling method of a core node.

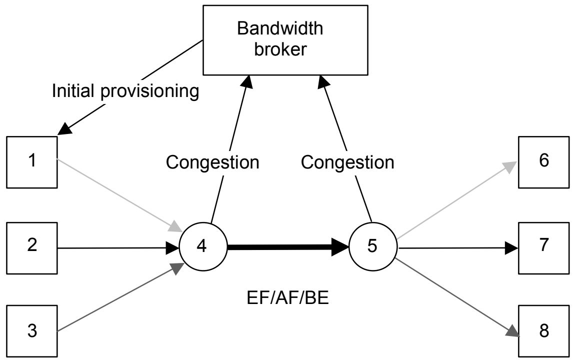


Fig. 7. Simulation model.

5) If the bandwidth broker receives a congestion notification or release message from the core node, it distributes a message to the ingress edge node that the starting point of the path goes through this core node.

IV. Performance Evaluation of the Proposed Mechanism

1. Simulation Model and Parameters

For the performance evaluation of the proposed mechanism, we used an ns-2 (network simulator) simulator. Figure 7 shows the peer-to-peer simulation model. It has three paths from each ingress edge node to each egress edge node. Each path has an initial bandwidth provisioning to EF/AF/BE services. We evaluate the blocking probability of each ingress edge node and packet loss probability of the core node and compare them with the static provisioning method. The static provisioning allocates a fixed bandwidth of the link to each service class and is not changed.

The node is loaded with exponentially distributed interarrival and holding times. The mean holding time is 30 s, the mean interarrival time is set to achieve load factor ρ. We define the

Table 2. Simulation parameters.

Scheduling algorithm	Priority scheduling
Session data	Traffic: exponential on-off model EF peak rate: 1 Mbps AF peak rate: 2 Mbps AF mean rate: 0.8 Mbps Mean holding time: 30 s Packet size: 100 B
Probe data	Traffic: CBR peak rate = 1 Mbps Measurement duration: 1 s Packet size: 100 B

input traffic load factor (ρ) = mean holding time/call attempt time interval. The target loss probability of the AF service is 10^{-3}, the end-to-end delay is 50 ms. Table 2 shows the simulation parameters.

We assume that the link capacity of the core node is 45 Mbps and the edge node is 15 Mbps. The initial provisioned path bandwidth of each service is 5 Mbps at the ingress edge node and 15 Mbps at the core node.

2. Simulation Results

Figure 8 shows the blocking probability of the proposed qDPM^2 mechanism compared to the static provisioning for EF and AF services. This simulation result shows that the proposed mechanism has less blocking probability than static provisioning even with a high traffic load. As the proposed mechanism can use the unused bandwidth of BE service through the movable boundary method, it can accept more requested flows. On the other hand, the static provisioning allocates a fixed bandwidth of the link to each service class and this allocated bandwidth is not changed.

Figure 9 shows the packet loss probability of the proposed mechanism for AF service when the traffic load is 5 and the buffer size is 500. Figure 9(a) shows that even though the proposed mechanism accepted more flows than static provisioning, the target loss probability (10^{-3}) of the AF service is guaranteed. Figure 9(b) also shows the effect of the congestion control scheme of the proposed mechanism. If a mechanism has not the proper congestion control scheme, the target loss probability cannot be satisfied when traffic load is 5.

Figure 10 plots the behavior of the average time delay according to the traffic load in the core node. This figure shows that even though the traffic load increases, the average waiting time of probing and data packets in the core node is below the maximum of 4 ms. This means that although the network is extended, the proposed mechanism guarantees the delay

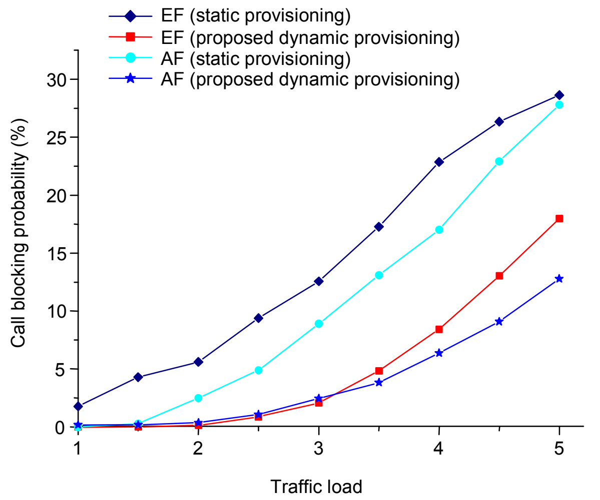
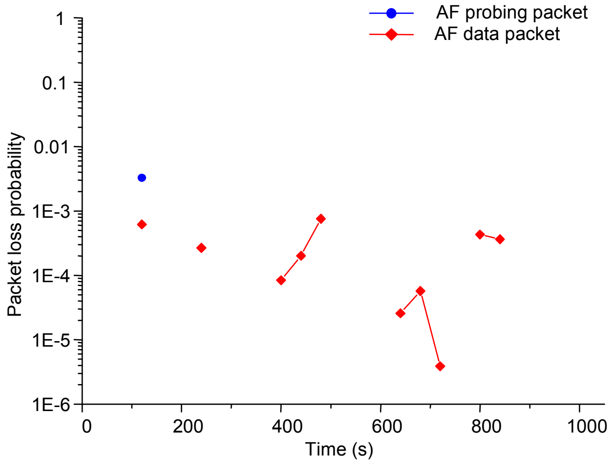
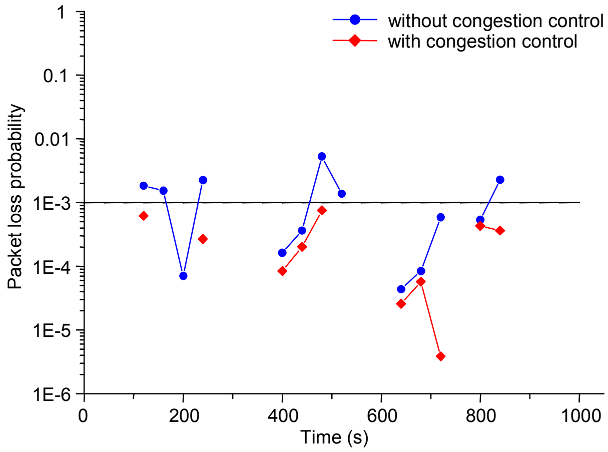


Fig. 8. Blocking probability of the proposed mechanism.



(a) Packet loss probability of proving and data packets.



(b) The effect of the congestion control scheme.

Fig. 9. Packet loss probability of the proposed mechanism.

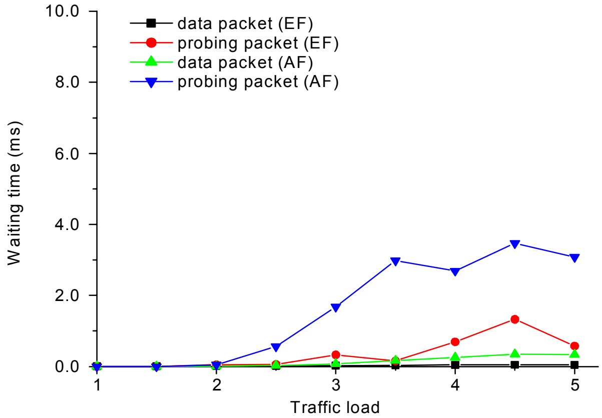


Fig. 10. Average waiting time for the proposed mechanism in the core node.

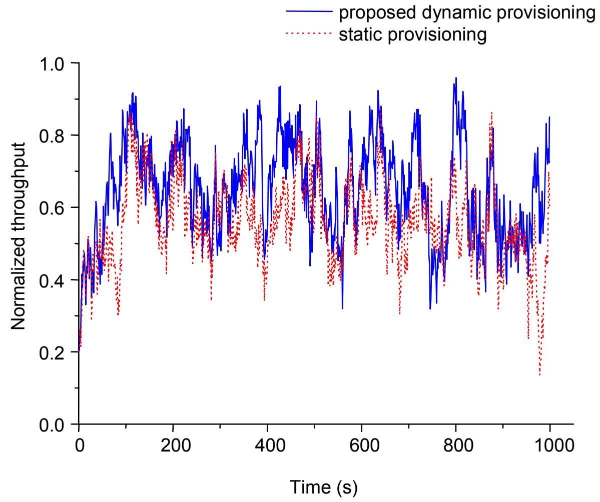


Fig. 11. Normalized throughput of the proposed mechanism.

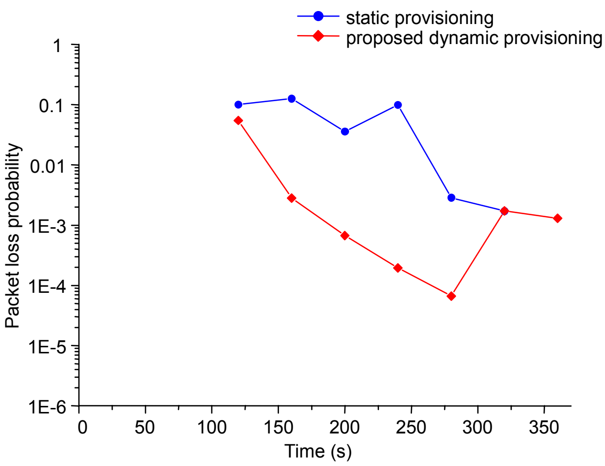


Fig. 12. Packet loss probability when unexpected traffic is inserted.

requirement of end-to-end performance.

Figure 11 plots the normalized throughput for the proposed mechanism and the static provisioning when the traffic load is 5. The normalized throughput is defined as the link bandwidth divided by the used bandwidth. This figure shows that the throughput with the proposed mechanism is higher than that with the static provisioning mechanism.

Figure 12 shows the packet loss probability of the static provisioning and the proposed qDPM^2 mechanism when unexpected traffic at 4 Mbps is inserted at the 100 s point for 200 s. This figure shows that the proposed mechanism can cope with an unexpected traffic insertion except at the beginning of a congestion period. However, the static provisioning mechanism cannot guarantee the target loss probability when unexpected traffic is inserted.

We compared the performance of the proposed mechanism with the static provisioning mechanism. However, since the proposed mechanism is based on dynamic provisioning, we

Table 3. Detailed processing of admission control for dynamic provisioning mechanisms.

	PoQ mechanism		Link base	qDPM^2 mechanism
Quota size	60	120		
Total flow arrivals	24,003	24,003	24,003	24,082
Total accepted flows	23,725	23,725	23,725	23,633
Total rejected flows	278	278	278	449
Blocking probability (%)	1.2	1.2	1.2	1.9
Flows accepted in normal mode	10,347	4,826	0	23,406
Acceptance probability in normal mode (%)	43.7	20.3	0	99.0
Flows accepted in critical mode	13,358	18,899	23,725	227
Acceptance probability in critical mode (%)	56.3	79.7	100	1.0

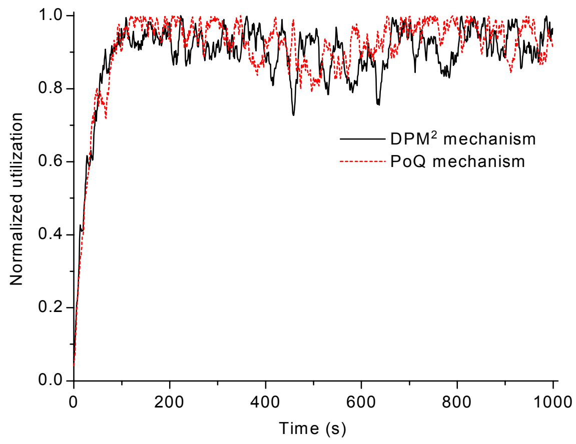


Fig. 13. Normalized throughput of dynamic provisioning mechanisms.

compared our mechanism with the PoQ mechanism of [16] and the link based dynamic provisioning of [13] using an ns-2 simulator. We used the simulation parameters in [16] so that we could make an exact comparison. Table 3 shows the simulation results of each dynamic provisioning mechanism for detailed flow processing of admission control when the normalized load is 1. Figure 13 also shows the comparison of normalized throughput between the PoQ mechanism and the proposed qDPM^2 mechanism.

As Table 3 and Fig. 13 show, although the proposed qDPM^2 mechanism has a higher blocking probability and a lower throughput than the existing dynamic provisioning mechanisms, it accepts most of the requested flows (99%) at the path level in the normal mode without any link-level bandwidth check. This means that the proposed mechanism has a scalability benefit when the network is large.

3. Complexity Evaluation

In this section, we provide a simple analysis of the complexity of the proposed mechanism and compare it with the PoQ mechanism and link-based dynamic provisioning mechanism. We measure the complexity of the proposed mechanism using the number of messages between the BB and each node during the admission control processing. The expected number of messages for the PoQ mechanism, Φ_{PoQ}, is defined as

$$\Phi_{PoQ} = Nrq\,(3 - Pr), \tag{1}$$

where Nrq is the number of set-up requested flows and Pr is reject probability.

In the PoQ mechanism, whenever a new flow is requested, the ingress edge node asks the BB whether it can be accepted and receives the response message. In addition, when a flow is released, a notice of the released information is sent to the BB. The link-based dynamic provisioning mechanism performs in the same manner as the PoQ mechanism in the admission control processing.

On the other hand, the expected number of messages of the qDPM^2 mechanism, Φ_{qDPM^2}, is defined as

$$\Phi_{qDPM^2} = E * Npe + \Sigma_{i=1}^{n}\,(Mc\,(1 + Ecp)), \tag{2}$$

where, E is the number of edge nodes, Npe is the number of paths in the edge nodes, Mc is the number of congestion notifications/release messages in the core node, Ecp is the number of edge nodes that has a path through the congested node, and n is the number of core nodes.

In the qDPM^2 mechanism, the message communication for the admission control occurs only with the initial path bandwidth distribution and a congestion notification/release. The first term of (2) is the number of initial path bandwidth distribution messages. The second term is the number of congestion notification/release messages from the core node to the BB and from the BB to each ingress edge node.

Second, we will provide a simple analysis of the proposed mechanism in terms of the number of accesses and updates in the bandwidth data table during the path-level and link-level admission control processing. The frequent bandwidth data table data access/update is a significant overhead when admission control is performed. The expected number of bandwidth data table accesses/updates of the link-based dynamic provisioning mechanism, Θ_{Link}, is defined in (3). In the link-based mechanism, whenever a set-up or release is requested, it accesses and updates the link bandwidth data of every node along the path.

$$\Theta_{Link} = K\,(Nrq\,(2 - Pr)), \tag{3}$$

where K is the number of nodes along the path.

The expected number of bandwidth data table accesses/updates in the PoQ mechanism, Θ_{PoQ}, is defined as

$$\Theta_{PoQ} = Nrq\,(2 + Pc - Pr) + (\varphi + \chi)\,(1 - Pr), \tag{4}$$

where φ is the quota allocation probability, χ is the quota de-allocation probability, and Pc is the acceptance probability in the critical mode. In the PoQ mechanism, we have to consider the probability that a flow set-up request triggers a quota allocation and the probability that a flow release request triggers a quota de-allocation.

Finally, the expected number of bandwidth data table accesses/updates in the qDPM^2 mechanism, Θ_{qDPM^2}, is defined as

$$\Theta_{qDPM^2} = Nrq\,(2 - Pr). \tag{5}$$

In the qDPM^2 mechanism, we only consider path-level bandwidth in terms of flow set-up and release request.

The simulation results of Table 4 demonstrate that the proposed qDPM^2 mechanism can reduce the number of messages between the BB and nodes when admission control is performed. This is because the existing dynamic provisioning mechanisms perform the admission control totally at the BB. However, since the proposed mechanism performs admission control for the path level at the ingress edge node, it can reduce the number of communication messages.

Additionally, for the number of accesses and updates in the bandwidth data table, the link-based dynamic provisioning mechanism must update all link bandwidth data of the node along the path within the BB domain. The PoQ mechanism must also access/update the path-level and link-level bandwidth data and additionally perform quota allocation and de-allocation processing. However, since the proposed mechanism only performs the path-level bandwidth management, it can reduce the number of accesses/updates of the bandwidth data.

Therefore, processing with a reduced complexity shows that the proposed mechanism has scalability and more effective deployment ability to an IP core network than existing dynamic provisioning mechanisms.

Table 4. Simulation results of the complexity analysis.

	# of messages between BB and nodes	# of data table access/update
Link base mechanism	71,731	143,284
PoQ mechanism	71,731	61,871
qDPM^2 mechanism	5,440	45,420

V. Conclusion

As we described in this paper, a DiffServ network has the drawback that it provides over provisioning to a particular service and low utilization. To achieve proper resource management, some researchers have recently studied the idea of using a bandwidth broker in DiffServ networks. However, so far, these studies have applied only a simple static provisioning mechanism, which could not adapt to a network situation with dynamically changing traffic and routing. Therefore, other studies investigated dynamic provisioning, which can properly allocate the network resources to the requested user flow according to the network situation. However, these dynamic provisioning mechanisms need complicated link-level bandwidth calculations.

To provide efficient network provisioning in a DiffServ network, we proposed the qDPM^2 mechanism based on a bandwidth broker and measurement-based admission control and movable boundary bandwidth management to support heterogeneous QoS services. This mechanism simplifies the calculation of the bandwidth data table in the bandwidth broker by performing only path-level resource management. Also, it has the advantage that the ingress edge node can perform the admission control for itself within the path-level bandwidth without any communication with the bandwidth broker. Additionally, when the path-level bandwidth allocated at the initial provisioning is fully occupied, the proposed mechanism performs the movable boundary management and MBAC for the link-level bandwidth management.

For the performance evaluation of the proposed mechanism, we presented simulation results in terms of blocking probability, loss probability, and throughput, comparing the proposed mechanism with static provisioning, and the number of communication messages and admission control processing complexity, comparing our mechanism with the existing dynamic provisioning mechanisms using an ns-2 simulator. Through simulation results, we proved that the proposed mechanism could guarantee user QoS requirements and provide bandwidth efficiency. We also showed that the proposed mechanism has scalability and more effective deployment ability to an IP core network than existing dynamic provisioning mechanisms.

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