Soft-State Bandwidth Reservation Mechanism for Slotted Optical Burst Switching

Author:

Guo, Jun; Um, Tai-Won; Choi, Jun Kyun; Ryu, Won; Lee, Byung Sun

Soft-State Bandwidth Reservation Mechanism for Slotted Optical Burst Switching Networks

Tai-Won Um, Jun Kyun Choi, Jun Guo, Won Ryu, and Byung Sun Lee

This paper proposes a novel transport network architecture for the next generation network (NGN) based on the optical burst switching technology. The proposed architecture aims to provide efficient delivery of various types of network traffic by satisfying their quality-of-service constraints. To this end, we have developed a soft-state bandwidth reservation mechanism, which enables NGN transport nodes to dynamically reserve bandwidth needed for active data burst flows. The performance of the proposed mechanism is evaluated by means of numerical analysis and NS2 simulation. Our results show that the packet delay is kept within the constraint for each traffic flow and the burst loss rate is remarkably improved.

Keywords: NGN transport network, soft-state bandwidth reservation, optical burst switching.

Tai-Won Um (phone: + 82 42 860 5205, email: twum@etri.re.kr) and Won Ryu (email: wlyu@etri.re.kr) are with the Broadcasting & Telecommunications Convergence Research Laboratory, ETRI, Daejeon, Rep. of Korea.

Jun Kyun Choi (email: jkchoi@icu.ac.kr) is with the School of Engineering, Information and Communications University, Daejeon, Rep. of Korea.

Jun Guo (email: jguo@cse.unsw.edu.au) is with the School of Computer Science and Engineering, The University of New South Wales, Sydney, Australia.

Byung Sun Lee (email: bslee@etri.re.kr) is with the IT Convergence Technology Research Laboratory, ETRI, Daejeon, Rep. of Korea.

I. Introduction

In the next generation network (NGN) [1], a broadband transport network connects various kinds of access networks and delivers everything from emerging real-time services to data-transfer services, and from asynchronous traffic to synchronous traffic. Packet-data services, mainly based on IP, can either use committed bandwidth or depend entirely on excess bandwidth for transport [2]. Most legacy services, on the other hand, rely on circuit-based point-to-point connections characterized by constant-bit-rate transmission. To meet networking demands on the *converged transmission* of the NGN, it is necessary for an NGN transport network to support quality-of-service (QoS) and flexible bandwidth management by exploiting optical switching capabilities that are generally used for broadband transmission [3], [4].

Optical burst switching (OBS) [5] is recognized as the most promising optical switching paradigm. OBS reserves core wavelengths for the duration of data bursts, thereby allowing wavelength sharing among different traffic flows. In addition, by processing the control information prior to data transmission, OBS avoids the complexities of optical packet switching, which requires large delay lines and fast processing of packet headers. A pioneering OBS proposal called just-enough-time (JET) [5] inevitably suffers from the optical burst loss problem due to the contention for optical resources among control packets within a core node [6]. To resolve the contention, a number of OBS reservation protocols have been proposed, including just-in-time (JIT) [7], wavelength routed OBS (WR-OBS) [8], and slotted OBS [9]-[11]. However, due to the intrinsic tradeoffs among burst loss rate, transmission delay, and link efficiency in dealing with data burst transmission, these OBS proposals resolve the contention problem at the

expense of transmission delay or link efficiency. As a result, such methods are only useful for limited-purpose network services and are unable to encompass complex demands for converged NGN transport networks.

In this paper, we propose a novel NGN transport network architecture, which provides converged transmission of various types of network traffic utilizing slotted OBS capabilities. An important element of the proposed architecture is a soft-state bandwidth reservation mechanism, which enables dynamic establishment of adjustable rate channels while satisfying QoS constraints and bandwidth flexibility through the NGN transport network.

The remainder of this paper is organized as follows. Background information is provided in section II. The proposed NGN transport network architecture and the multi-service OBS node architecture are described in section III. In section IV, we propose the soft-state bandwidth reservation mechanism, which provides flexible bandwidth reservation for various types of network traffic. Section V investigates the performance of the multi-service burst assembly and the soft-state reservation mechanism by means of numerical analysis and NS2 simulation. Finally, we summarize our results in section VI.

II. Background

In this section, we provide the necessary background to the context of this paper. Section II.1 explains basic terminology and issues in OBS networks. Reservation methods relevant to an NGN transport network are provided in section II.2.

1. Basics of OBS

In an OBS network, IP packets destined for a common egress node are assembled into data bursts at an ingress node. A control packet precedes each burst by a time offset, and is electronically processed at a succession of OBS nodes to reserve a contiguous sequence of wavelength channels for the pending burst. Then, depending on the type of OBS deployed, the pending burst is entirely switched in the optical domain, either with or without acknowledgement.

Slotted OBS [9]-[11] is a form of OBS where the time is essentially quantized into discrete units referred to as slots. The chance of contention in slotted OBS using JET signaling is smaller than in JET-OBS because the behavior of the bursts is more predictable and regulated [9]. A pre-established lightpath through the slotted OBS network can be useful for transmitting synchronous traffic like SONET/SDH [10]; however, making a ligthpath for transmitting short-lived or bursty data traffic is inefficient and costly from the perspective of link bandwidth

utilization.

Techniques for burst assembly at the ingress node are classified into timer-based [12] and size-based [13]. Timer-based algorithms are suitable for time-constrained traffic since an upper bound on the burst assembly time is enforced. For non-time-constrained bulk traffic, the objective is to improve transmission efficiency, despite a longer burst assembly time. The round-robin burst assembly algorithm proposed in [14] is a technically simple and feasible method. It works by classifying packets into assembly queues according to their egress nodes, and transmitting the assembled bursts in a round-robin order without consideration of transmission efficiency. Due to the large number of packet aggregations at ingress nodes and the absence of buffering delay at core nodes in an OBS network, the end-to-end delay performance is mainly dominated by the burst assembly technique at the ingress node.

2. Bandwidth Reservation for NGN Transport Networks

Reservation signaling methods are typically classified into soft-state and hard-state methods. A state is *soft* if it is maintained by network nodes and if it expires after a certain time interval unless it is refreshed by an update message. On the contrary, in *hard-state* signaling, an installed state remains installed unless it is explicitly removed by the receipt of a release message. Hard-state signaling requires complex interactions among many different distributed nodes, and an exceptional condition must be explicitly engineered [15].

The soft-state method has been chosen for many Internet protocols, including RSVP [16], SIP [17], IGMP [18] and so forth. The reason soft-state signaling has been utilized so often is that it works well in practice. This method provides robust and flexible operation of reservation signaling for a dynamically operated network environment with the change of the network configuration, routing update, node failure, and addition or removal of nodes. For these reasons, soft-state signaling would be appropriate for the NGN, where heterogeneous network components would be mixed together. Once adopted, it would operate well in the NGN environment.

III. Proposed NGN Transport Network Architecture Based on Slotted OBS

1. NGN Transport Network and Node Architecture Based on Slotted OBS

In an NGN transport network located in a metro or core area, various types of client networks based on IP, MPLS, SONET/SDH, ATM, Ethernet, and so on could be connected to the NGN transport network through a multi-service OBS edge node as shown in Fig. 1. Multi-service OBS edge nodes
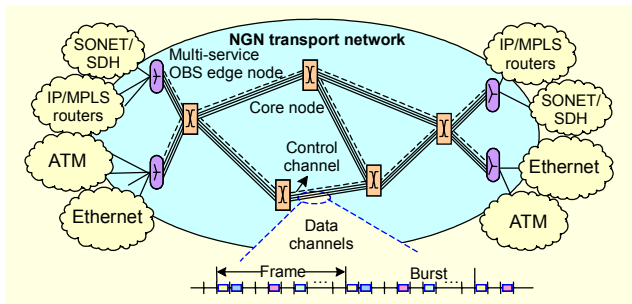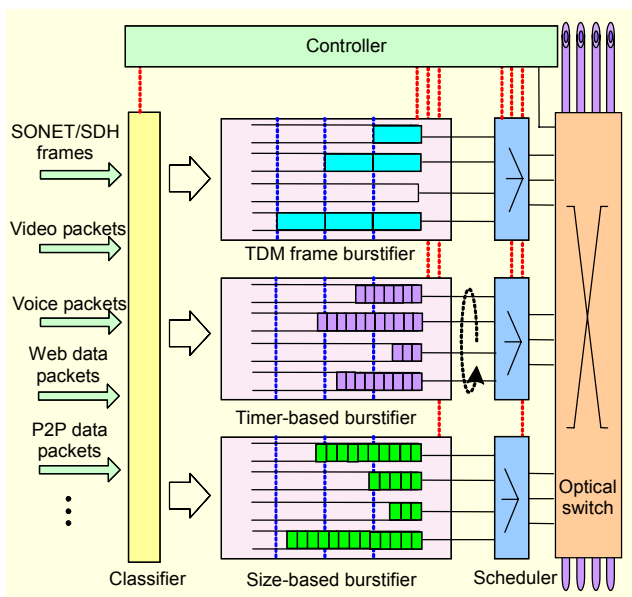
Fig. 1. Network reference model.

Fig. 2. Architecture of a multi-service OBS edge node.

and OBS core nodes are interconnected by WDM fibers, which contain wavelength channels. The bandwidth of each wavelength is organized into a series of frames, each of which is sub-divided into fixed length time-slots.

The proposed multi-service OBS edge node employs both electrical and optical technologies and plays an essential role in multi-service convergence. It aggregates a diversity of data traffic from emerging real-time services to legacy data-transfer services and from asynchronous transmission to synchronous transmission. The aggregated traffic is then translated into optical bursts appropriate for transmission through the core OBS nodes. The multi-service OBS edge node consists of a traffic classifier, a multi-class burst assembler, a scheduler, and an optical switch as shown in Fig. 2.

Data packets, such as IP packets, ATM cells, SONET/SDH frames, Ethernet packets, and so on, are injected into the classifier at the ingress multi-service OBS node. The classifier sorts and forwards incoming data packets into corresponding burstifiers for aggregation on the basis of traffic type, destination, loss and delay specifications. The data packets are

placed in the burstifier queue where they are assembled into bursts according to the multi-class burst assembly algorithm. When that is done, the bursts are scheduled for transmission in the scheduler over the switch fabric. A control packet precedes each burst by a time offset. Once assembled at the ingress node, an optical burst is able to transparently travel any distance via core nodes before it arrives at an egress node, where the optical burst is disassembled and the data packets are forwarded to the client networks.

The core node consists of a switch controller and an optical switch. The switch controller creates and maintains a forwarding and reservation table, and is responsible for configuring the optical switch. When the switch controller receives a control packet, it identifies the intended destination and searches the forwarding and reservation table to find the intended output port. If the output port is available when the data burst arrives, the switch controller configures the optical switch to let the data burst pass from incoming time-slots to time-slots on the output port while satisfying the QoS requirement of each data burst flow.

In the proposed NGN transport network architecture, the core node performs a novel scheduling mechanism, called *soft-state bandwidth reservation* (SSR), to dynamically reserve bandwidth for arriving burst flows by cooperating with the multi-service edge node using a multi-class burst assembler.

Since switching is done in a slot-by-slot manner, all incoming slots in different input ports must be aligned with the local time-slot before entering the switching network. This alignment can be done by using optical input synchronizers. For a detailed description of the optical input synchronizer, see [19] and references therein.

In an NGN transport network, data traffic of the order of tens of gigabytes will be delivered through edge nodes and core nodes. A burst flow is distinguished by a pair of ingress/egress node addresses instead of a pair of source/destination IP addresses; thus, it is of relatively coarse granularity compared with an IP flow. Although the amount of incoming traffic can fluctuate with time, a certain amount of traffic will pass between a pair of ingress/egress nodes in the NGN transport network.

2. Multi-class Burst Assembly

The multi-class burst assembler of the multi-service OBS edge node aggregates various types of data packets into optical bursts for transmission over NGN transport networks. In aggregating data packets, it takes into account the QoS classification of each packet, such as packet loss rate, delay constraints, and transmission efficiency. The multi-class burst

assembler contains three types of burstifiers: TDM frame, timer-based, and size-based. After receiving a data packet, the multi-class burst assembler checks the traffic type and attributes of the data packet, and forwards it into an appropriate burstifier. Once a burst is created by the burstifier and its corresponding scheduler according to its burst assembly method, the burst is sent to the output port. The packet loss probability can be reduced by using scheduling methods, which actually cooperate with the proposed SSR mechanism performed at core nodes.

A. TDM Frame Burstifier

The TDM frame burstifier supports burst-framing and transmission of TDM frames arriving from legacy SONET/SDH client networks. One or more TDM frames can be encapsulated by using a framing device capable of mapping SONET/SDH frames into slotted burst payloads. The slotted burst in the burstifier queue is scheduled for transmission in a round-robin order. Consequently, the TDM frame burstifier periodically generates slotted bursts aligned with a slot boundary. The number of incoming TDM frames determines the allocated number of slots, which is expected to be constant on each successive time-slot for a long period.

By cooperating with this TDM frame burstifier, the core nodes using the proposed SSR mechanism are able to reserve slots for the periodic TDM burst flows.

B. Timer-Based Burstifier

The timer-based burstifier is able to guarantee the delay bound of multimedia packets. Packets from the classifier output are queued and fitted into slotted bursts after aggregation in keeping packet delay tolerance. If the size of buffered packets is smaller than the queue size, an arriving packet is admitted, otherwise it is lost.

When the round-robin scheduler is used, a burst is assembled during the round-robin cycle time. Then, the scheduler determines whether to send the assembled burst at the slot boundary. The generic framing procedure could be applied in order to map and handle data packets of different bit rates efficiently into a slotted burst payload.

C. Size-Based Burstifier

This size-based burstifier fills up a slot with packets to improve the transmission efficiency without considering the delay bound. It utilizes the slot size as a parameter to determine the number of packets to be assembled in a slotted burst. At the time-slot boundary, the number of slots, which are filled up with packets, could be sent. If no slot is filled up with packets at a time-slot boundary, the scheduler does not send any burst.

IV. Soft-State Bandwidth Reservation Mechanism

1. Soft-State Bandwidth Reservation Mechanism

The core OBS nodes support differentiated QoS for guaranteed quality. Cooperating with the multi-class burst assembler at ingress nodes, the SSR mechanism in core nodes enables dynamic bandwidth provisioning in the NGN transport network.

Upon receiving control packets with periodicity, the core node examines the ingress/egress address pair of the burst and determines an outgoing port and a slot for the burst to be sent to a next node. At first, the core node checks whether there has been a reserved slot on a reserved outgoing wavelength channel for the arriving burst. If the core node finds a reserved slot for the arriving burst, it will send the burst through the reserved slot. If there is no reserved slot, the core node will try to find an available slot among unreserved outgoing slots. When an available outgoing wavelength channel and a slot are determined, the burst is sent via the internal switch fabric to the outgoing channel and the slot. If neither an available outgoing wavelength channel nor a slot can be found for burst transmission, the core node will try to use the internal fiber delay line (FDL) buffer to delay the burst transmission. If the FDL buffer is full, the burst is dropped.

After the burst is successfully sent, the core node records the ingress/egress address of the burst, the outgoing wavelength channel and the slot number used to send the burst in its arrival-record table. By checking the transmission records of the arrival-record table, the SSR reservation scheduler knows that the slot numbers used to transmit bursts corresponding to a specific ingress/egress address pair. Thus, it can recognize the periodicity of those slot numbers being used. A repetition counter is used to judge the periodicity of burst transmission from an ingress node to an egress node.

Once the periodicity of burst transmission is determined, the SSR reservation scheduler knows that a certain ingress node requests a bandwidth reservation for its periodic burst flow, so it performs a slot reservation on the upcoming frames for the duration recorded in a certain max-reservation counter.

Figure 3 shows the flow chart of the SSR mechanism. In previous reservation methods, reservations are either made or denied end-to-end. Our method allows a partial reservation, in which some links may have resource reservation for a particular burst flow while others may not. On links without reservation, bursts are carried on a best-effort basis, and the SSR request continues downstream towards the egress node.

Basically, the proposed SSR method provides no feedback to the ingress node as to what the reservation has successfully performed. However, by optionally adding feedback in the form of *slot collision reports* to detect and correct slot collision
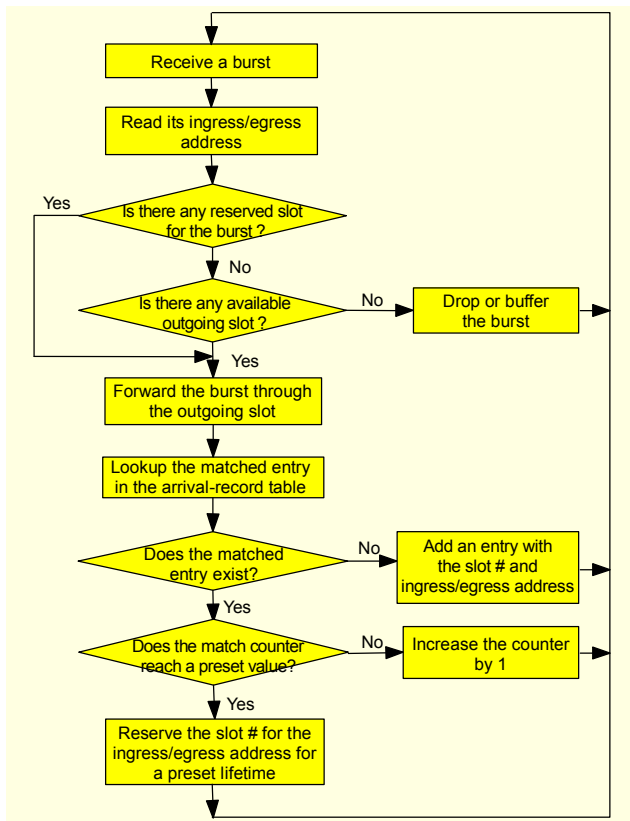
Fig. 3. Soft-state bandwidth reservation mechanism.

in a core node, the SSR method is able to further reduce the burst loss rate in the NGN transport network.

When a core node recognizes that a newly arriving burst flow is trying to reserve a time-slot that was reserved by another flow, it optionally sends a notification message to inform the corresponding ingress node that its bursts have been blocked. A loss counter is used to find the periodicity of lost bursts with the same ingress/egress address. Upon receiving the blocking notification message from the core node, the ingress node reads the blocking notification message and recognizes the loss of bursts that it has sent. Consequently, the ingress node randomly changes the slot location for transmitting bursts in order to avoid burst collision, where the same slot number must not be allocated again.

2. Advanced Features of SSR

A. Burst Buffering

Although the SSR method does not mandate the use of FDLs, its QoS performance can be significantly improved even with limited FDLs to resolve contention for bandwidth among multiple bursts. When burst collision occurs because there is no available outgoing slot, the core node can try to allocate the blocked burst in later outgoing slots by using FDLs,

which store one or more bursts and delay transmission.

Once the SSR mechanism is performed with FDLs, the priority of the burst buffered in the FDLs is set lower than that of non-buffered bursts. This way, it prevents the loss of non-buffered bursts due to competition with buffered bursts. Ongoing burst flows, which are reserved by the SSR method through the NGN transport network, are not disturbed by newly arriving burst flows or best-effort single bursts.

The SSR reservation scheduler needs to increase the loss counter and inform the ingress node that its burst has been blocked or buffered. With this notification, the ingress node is able to find an available slot through a core node and make a reservation for its burst flow. It also may reduce the end-to-end delay and delay-variance for burst transmission.

B. Optical-Electronic-Optical (OEO) Switching

In an NGN transport network capable of optical-electronic-optical (OEO) switching, header information can be carried within a burst, while the information required for routing and reservation is separated from the data burst and sent as a burst control packet before the data burst is sent in all-optical NGN transport networks. When a core node receives the burst containing ingress/egress address information, it can perform the proposed SSR reservation as well as routing and forwarding.

Whether the SSR mechanism is applied to the all-optical switching networks or OEO switching networks, the applied mechanism in both switching types is the same. The only difference is that the soft-state reservation is performed after the data burst is received in OEO switching and before the data burst is received in all-optical switching.

V. Performance Analysis

In this section, we present the performance analysis of the proposed multi-class burst assembly and the SSR mechanism.

1. Performance Analysis of the Multi-Class Burst Assembly

An important performance aspect of the multi-class burst assembly is individual packet delay in each burstifier queue. In a timer-based burstifier queue, the packet delay should be bounded within the constraint of an application service. The packet delay in a size-based burstifier queue also needs to be investigated for determining availability to transmit best-effort traffic. Next, we discuss the mathematical derivation of the packet delay distribution in the multi-class burst assembler, where each burstifier has a finite queue size and its burst-emission depends on the total number of packets in the queue.

In the TDM frame burstifier model, the amount of burst-emission on each successive time frame/slot is deterministic.

The delay of a TDM frame finding a certain number of TDM frames ahead of it, under the first-come-first-served (FCFS) queuing discipline, is therefore bounded.

However, in the timer-based and size-based burstifier models, the exact number of packets that can be sent in a burst is random at each successive time frame/slot and depends on the number of waiting packets. If there is a positive probability that the waiting packets will not receive service within a time frame/slot, the delay of a packet can be arbitrarily large, despite the fact that the packet arrives at a burstifier queue with a finite number of packets ahead of it.

We assume that the processing time to generate a burst at each burstifier queue is constant. With the round-robin scheduler, the cycle time to run around all queues in a round-robin method is given by T. Therefore, in each burstifier queue, the time axis is divided equally into successive frames/slots of length T. A burst is assembled during the cycle time T, and then the scheduler determines whether to send the assembled burst at the slot boundary.

Packets arrive at the multi-service OBS edge node from the access networks. Let the packets arrive at each burstifier queue according to a homogeneous Poisson process of rate λ. If there are fewer than K packets present, an arriving packet is admitted; otherwise, it is lost. A packet admitted during $(0, T)$ may be removed at one of the epochs kT, $k \geq 1$. If it is admitted at time $T-u$, $0<u<T$, its delay is the sum of u and $(k-1)T$. At the end of a time interval T, the burstifier queue will contain j, $1 \leq j \leq K$, packets. The i packets, $0 \leq i \leq j$, are transmitted out of the buffered j packets. The remaining $j-i$ packets remain in the burstifier queue and will be considered for transmission in the subsequent slot. Let $d(i, j)$ define the probability that i of the j packets can be sent on an FCFS basis. The quantities $\{d(i, j)\}$ satisfy

$$\sum_{i=0}^{j} d(i, j) = 1. \tag{1}$$

As described in subsection III.2, there are three different types of the burst-emission processes in accordance with the specific QoS requirements in the multi-class burst assembler. In these burstifiers, more slots are allocated to one burst where the demand is higher, so that the longer the queue is in terms of the number of packets, the more packets are served through burst-emission.

For the TDM frame burstifier and the timer-based burstifier, the quantities $\{d(i, j)\}$ are set as follows.

$$\begin{cases} d(j, j) = 1, & \text{for } 0 \leq j \leq N, \\ d(N, j) = 1, & \text{for } N \leq j \leq K, \\ d(i, j) = 0, & \text{elsewhere}. \end{cases} \tag{2}$$
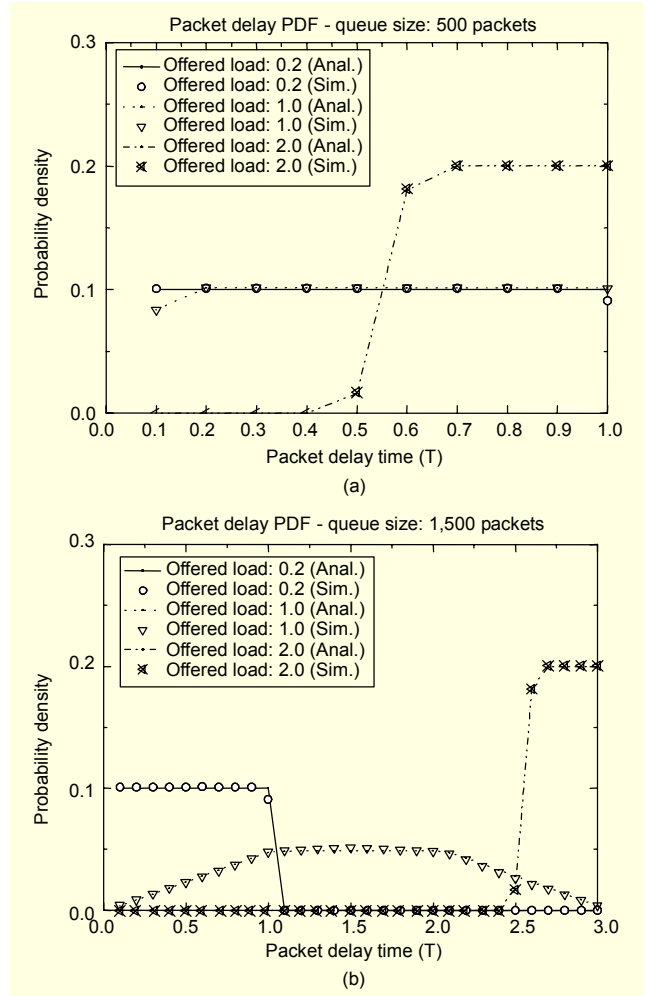

Fig. 4. Packet delay PDF in the timer-based burstifier with (a) 500-packets buffer and (b) 1,500-packets buffer.

Let $M=\lceil K/N \rceil$, where $\lceil x \rceil$ is the smallest integer larger than or equal to x. If there are N or more packets in the queue at the end of a time-slot, N packets are transmitted through a burst; otherwise, all packets in the queue are transmitted. Thus, the delay of an arbitrary admitted packet is bounded by MT.

More specifically, if $N=1$, it further reduces to the TDM frame burstifier, where one SONET/SDH frame is filled in a slotted burst. The delay of the TDM frame is deterministic (see [20]). In this paper, we focus on the analysis of the timer-based and size-based burstifiers.

For the size-based burstifier,

$$\begin{cases} d(N, j) = 1, & \text{for } N \leq j \leq K, \\ d(i, j) = 0, & \text{elsewhere}. \end{cases} \tag{3}$$

With the size-based burstifier, if there are N or more packets at the end of a time-slot, N packets are transmitted through a burst; otherwise, the packets will remain in the burstifier queue.
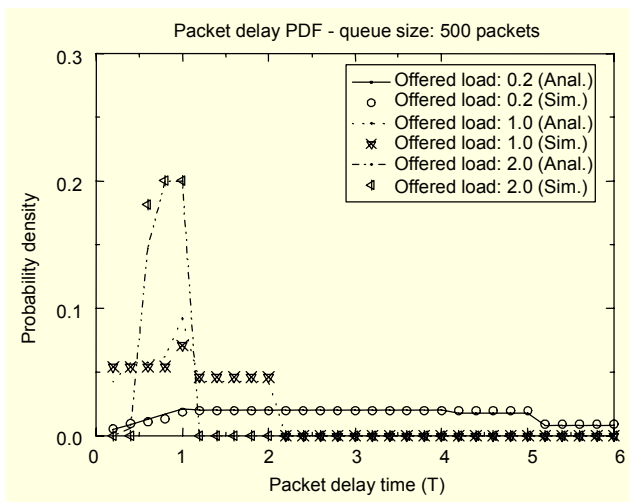
Fig. 5. Packet delay PDF in the size-based burstifier.

In [21], the authors derive the result that the delay density of a TDMA model with state-dependent service is given by a finite, positive linear combination of beta densities. The coefficients of those linear combinations are computed by a recursive scheme. Given the probability $\{d(i, j)\}$, the analysis can be applied to determine the queuing delay distribution of an arbitrary packet, that is, the distribution of the interval between its arrival time and the time it has been scheduled for transmission.

A maximum of 500 packets can be sent by burst-emission during each frame/slot. That is, $N = 500$, and the timer-based burstifier queue can store a maximum of 500 or 1,500 packets. The size-based burstifier queue is able to contain a maximum of 500 packets.

Figure 4 shows the performance results on ingress queuing delay of the timer-based burstifier as a function of the offered load.

In Fig. 4(a), packets are aggregated in a timer-based burstifier queue during a frame period T, and the aggregated packets are sent at every frame/slot boundary. Therefore, the packet delay is bounded by T. However, the packet delay distribution in the burstifier queue varies with the offered load. When there is a low offered load, the packet delay of an arbitrarily admitted packet is evenly distributed over T duration. As the offered load increases, the burstifier queue would be occupied earlier by arriving packets, which may wait longer for the frame/slot boundary. In Fig. 4(b), packets are aggregated during $3T$, and the aggregated packets are transmitted at every $3T$ boundary. The packet delay in this burstifier queue is bounded by $3T$. However, arriving packets when there is a high offered load may wait longer than in a low offered load.

Figure 5 shows the packet delay distribution in a size-based burstifier queue as a function of the offered load. When there is a high offered load, the delay of an arbitrarily admitted packet

is almost bounded by T because the burst can be sent as soon as it is filled with packets. However, if the offered traffic load in the size-based burstifier queue is low, the delay PDF of an arriving packet is almost constant over the aggregation period. An early-admitted packet should wait until the burst is fully filled with packets. At the expense of aggregation delay, transmission efficiency can be improved in the size-based burstifier of the multi-class burst assembler.

2. Performance Analysis of the Soft-State Bandwidth Reservation Mechanism

We implemented new SSR modules in the NS2 simulator to evaluate the performance of the proposed method [22]. In the simulation, nodes are connected by WDM links with multiple wavelength channels carrying bursts. The node is capable of wavelength conversion, and the transmission rate of each wavelength is 10 Gbps. The wavelength is organized into a series of frames, each of which is sub-divided into fixed length time-slots set to 0.125 ms (sufficiently large to contain a SONET/SDH frame) and each time-slot contains about 156 kb of data in one burst.

It is assumed that bursts generated by a size-based burstifier of the multi-class burst assembler arrive at a node according to a Poisson process per time-slot. Burst flows generated by the TDM frame burstifier or timer-based burstifier arrive at the node according to a Poisson process. We also assume that one frame consists of 5 slots, and for a burst flow, bursts are periodically transmitted every 5 slots. The simulation results were obtained for JET-OBS, slotted OBS, and the proposed SSR mechanism. The performance metric is the burst loss probability as a function of the offered input traffic load, the length of burst flows (that is, the number of bursts on a flow), applied FDL size, and SSR parameters, such as the reservation counter and loss counter.

Figure 6 shows the burst loss rate of JET-OBS, slotted OBS, and the proposed SSR method as a function of the offered traffic load per ingress OBS node and the length of burst flows. In case of the SSR mechanism, the reservation counter and loss counter are set to 2 and 3, respectively. Comparing the burst loss rate of JET-OBS and slotted OBS with the SSR mechanism shows that the burst loss rate of the SSR is markedly improved. As the flow length increases from 50 bursts to 400 bursts in the SSR mechanism, the burst loss rate greatly decreases. At the beginning of a newly arriving burst flow, the bursts comprising the flow may experience burst collision for the slot reservation. Once core nodes recognize the periodicity of bursts and execute the SSR reservation for the subsequent bursts of the flow, the subsequent bursts do not suffer blocking. Consequently, the overall burst loss rate of
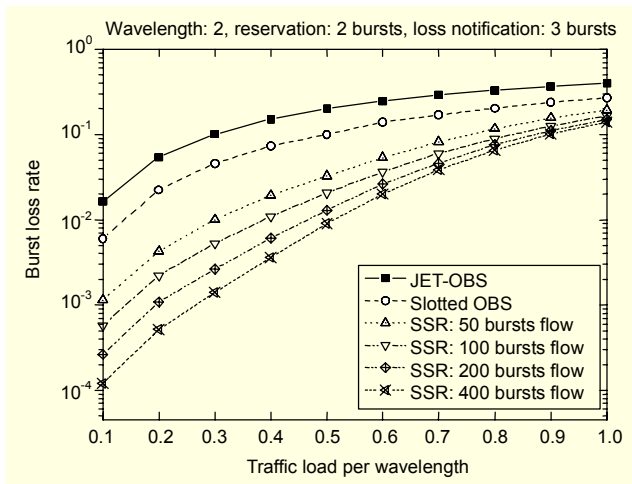
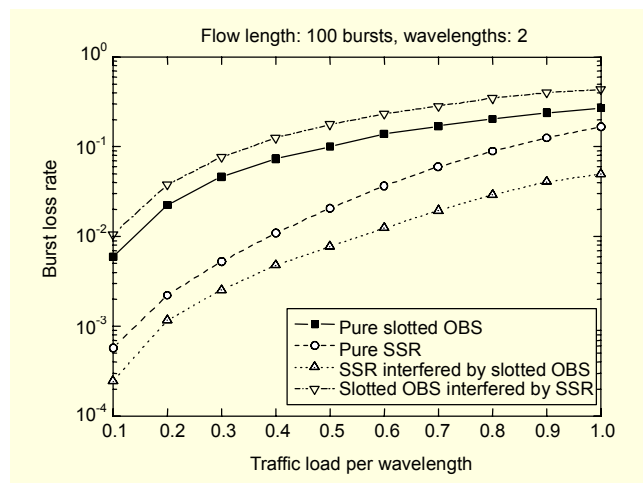Fig. 6. Burst loss rate vs. offered load with various flow lengths.

Fig. 7. Burst loss rate vs. offered load with various wavelengths.

Fig. 8. Burst loss rate vs. offered load with various numbers of FDLs.

Fig. 9. Burst loss rate of mixed traffic with single bursts and periodic burst flows.
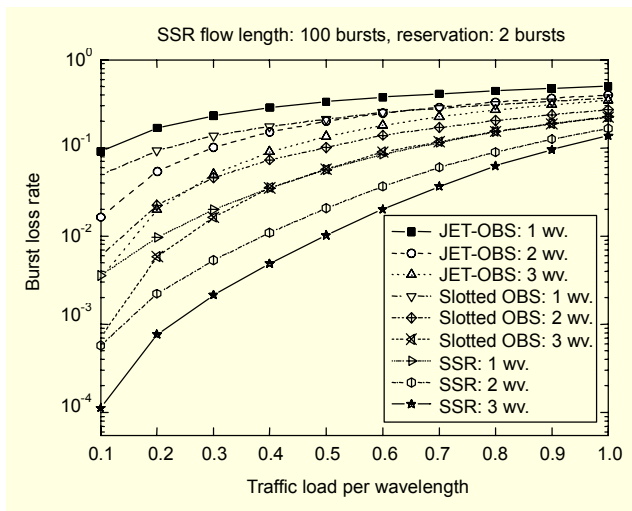

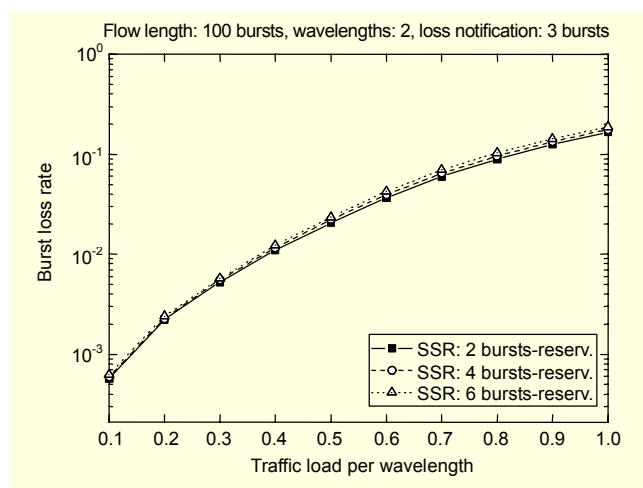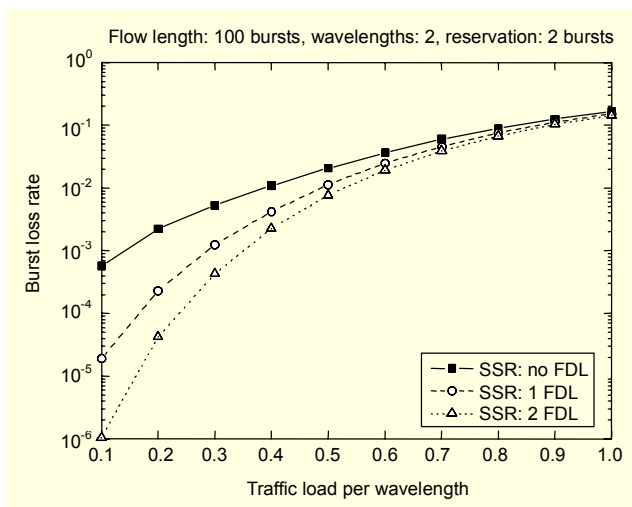
Fig. 10. Burst loss rate vs. offered load with various reservation counter values.
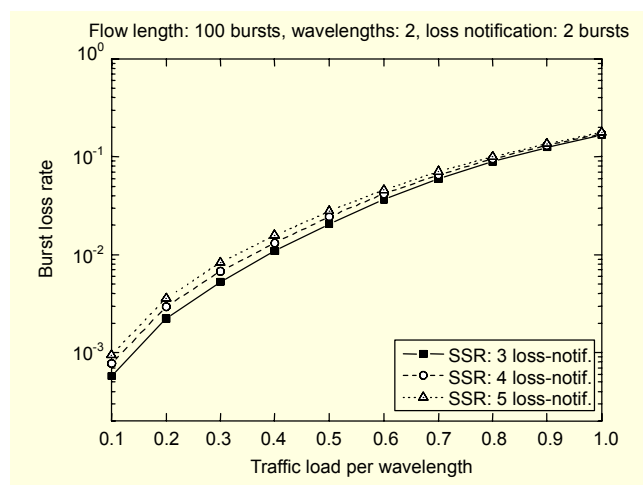

Fig. 11. Burst loss rate vs. offered load with various loss counter values.

long-lived burst flows is relatively lower than that of short-lived burst flows.

Figure 7 shows the burst loss rate with various numbers of wavelengths. Notice that the burst loss rate drops more quickly than the used wavelength increases when compared with JET-OBS and slotted OBS. When burst collision occurs at an output of a node, the blocked burst could be stored in the FDLs and be allocated in the next available slot. Figure 8 shows the burst loss rate of the SSR method with various values of FDL. With the FDLs, the burst loss rate can be decreased dramatically. While it is certainly possible to improve burst loss rate by allowing bursts to use more than two FDL buffers, we did not consider that possibility here because it is costly and difficult to implement.

To show the effect of differentiated processing achieved by the SSR method, the burst loss rates experienced by mixed traffic with single bursts and periodic burst flows, which contend for the same output link at a node, are presented in Fig. 9. These results were obtained by assuming that half of the offered traffic load is sent from the TDM frame burstifier or timer-based burstifier and the other half follows the traffic pattern of slotted OBS, which is generated by the size-based burstifier. Where periodic burst flows cause interference, the loss rate of single bursts using slotted OBS is higher than that of the pure slotted OBS. Because single bursts using slotted OBS do not invoke the reservation mechanism of the SSR scheduler, they are allowed to be transmitted through time-slots unoccupied by periodic burst flows. On the contrary, when periodic burst flows are mixed with single bursts, their loss rate is lower than when the offered load is entirely made up of periodic burst flows because those suffer less competition with other periodic burst flows for time-slot reservation.

As described in section IV, once the periodicity of received bursts is recognized at a core node, its SSR scheduler performs slot reservations on the upcoming frames for the duration recorded in a certain max-reservation counter. Figure 10 shows the effect with various max-reservation counter values. In order to distinguish the different effects of the max-reservation counter, we set the flow length to 100 bursts and investigate its burst loss rate. As the number of reserved slots increases, the burst loss rate increases. Although a burst flow has finished, the reserved slots for the burst flow cannot be used for other bursts. Therefore, if the max-reservation counter is set to a large value for short-lived burst flows, it will waste the channel resources.

When a core node recognizes that a newly arriving burst flow is trying to reserve a time-slot reserved by another flow, it sends a notification message to the corresponding ingress node. A loss counter is used to find the periodicity of lost bursts with the same ingress/egress address. As shown in Fig. 11, the lower the loss counter set, fewer bursts are lost because the loss notification is quickly sent to the ingress node. However, if the loss counter value is set too low, this may induce core nodes to generate notification messages in response to the loss of non-periodic single bursts.

In the second scenario, we simulate and analyze a more complex network using the SSR mechanism and slotted OBS by using the NS2 simulator. Figure 12 presents an NSFNET topology consisting of 19 OBS nodes and 10 routes. The routes are selected by considering a variety of path lengths and the degrees of link sharing among burst flows. The link delay between neighbor nodes is set to 1 ms. The traffic source model and link condition are the same as in the previous scenario. The simulation results are obtained for the slotted OBS and the proposed SSR mechanism. In this configuration, we evaluate the burst loss rate and the effectiveness of the SSR mechanism over multi-hop paths.

Figure 13 shows the overall blocking probability in the

R_1: 1→2→5→7→15→19 R_6: 9→4→6→16→17
R_2: 3→10→11→12→14 R_7: 10→11→12→13→16→17→18
R_3: 5→7→6→8→13 R_8: 2→4→9→8→12→14
R_4: 6→8→12→11 R_9: 12→8→6→4
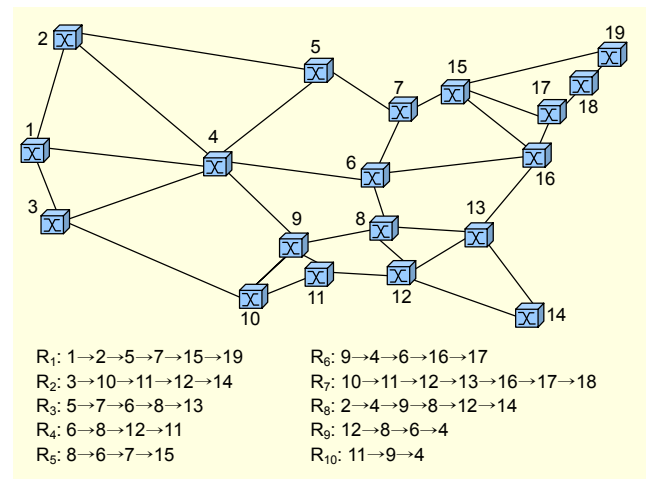R_5: 8→6→7→15 R_{10}: 11→9→4
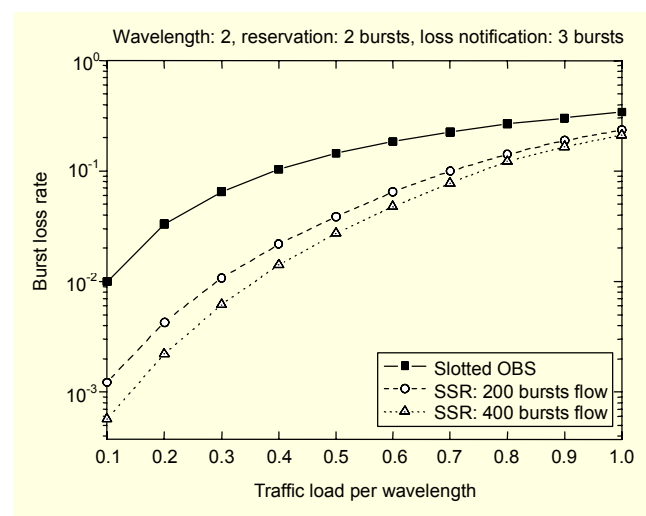
Fig. 12. 19-node NSFNET topology.

Fig. 13. Overall blocking probability.

studied NSFNET topology. The SSR method improves the burst loss rate by more than one order of magnitude in the region of low offered loads in comparison with the burst loss rate with slotted OBS. In the SSR method, the hop count from the ingress node to the egress node has an effect on the burst loss rate. As mentioned previously, bursts could be blocked during the initial reservation period. If the hop count increases between an ingress node and an egress node, the total burst loss probability is increased. Moreover, as the number of hops increases, the collision-recognition time of the collision notification from a core node to an ingress node increases. Consequently, more bursts may be lost when blocking occurs as the hop count increases. In the proposed SSR method, once the SSR scheduler recognizes the periodicity of the slotted burst, it reserves slots for the subsequent bursts. Therefore, if the length of burst flow increases more than 400 bursts, the overall burst loss rate will be greatly decreased. On the other hand, if the flow length decreases by one slot, the burst loss rate of the SSR method is close to that of the conventional slotted OBS.

VI. Conclusion

We have proposed a novel NGN transport network architecture, which can provide a flexible and efficient platform for convergence of packet-based and circuit-based network traffic based on slotted OBS capabilities.

The proposed architecture consists of two main parts: the multi-class burst assembly at ingress nodes and the soft-state bandwidth reservation (SSR) mechanism at core nodes. The multi-class burst assembly mechanism guarantees the delay bound of packets and improves the transmission efficiency. The SSR mechanism provides QoS guarantee and flexible bandwidth management over the NGN transport networks without any complex signaling or offset-based reservation. By comparing the proposed architecture with JET-OBS and slotted OBS, we demonstrated that the burst loss probability of the proposed SSR mechanism can be improved by more than one order of magnitude. The proposed architecture could be used to build an NGN transport network, providing efficient delivery of various types of network traffic, while satisfying QoS constraints and bandwidth flexibility.

References

[1] "Next Generation Network Global Standards Initiative (NGN-GSI)," http://www.itu.int/ITU-T/ngn/.

[2] M. Cvijetic, D. Suarez, and S. Nakamura, "Handling Multiple Services in Today's Converged Network Environment," NET whitepaper, http://www.necam.com/onsd/collateral/.

[3] H.-H. Lu, W.-S. Tsai, T.-S. Chien, S.-H. Chen, Y.-C. Chi, and C.-W. Liao, "Bidirectional Hybrid DWDM-PON for HDTV/Gigabit Ethernet/CATV Applications," *ETRI Journal*, vol. 29, no. 2, Apr. 2007, pp.162-168.

[4] K.-H. Ahn, K.-E. Han, and Y.-C. Kim, "Hierarchical Dynamic Bandwidth Allocation Algorithm for Multimedia Services over Ethernet PONs," *ETRI Journal*, vol. 26, no. 4, Aug. 2004, pp. 321-331.

[5] M. Yoo, C. Qiao, and S. Dixit, "QoS Performance of Optical Burst Switching in IP-Over-WDM Networks," *IEEE JSAC*, vol. 18, no. 10, Oct. 2000, pp. 2062-2071.

[6] J.-P. Park and M.-S. Lee, "Simultaneous Burst and Burst Control Packet Transmission Protocol for Optical Burst Switching Ring Networks," *ETRI Journal,* vol. 29, no. 1, Feb. 2007, pp. 116-119.

[7] J. Y. Wei and R. I. McFarland, "Just-In-Time Signaling for WDM Optical Burst Switching Networks," *IEEE JLT*, vol. 18, no. 12, Dec. 2000, pp. 2109-2031.

[8] M. Duser and P. Bayvel, "Analysis of a Dynamically Wavelength Routed Optical Burst Switched Network Architecture," *IEEE JLT*, vol. 20, no. 4, Apr. 2002, pp. 574-585.

[9] J. Ramamirtham and J. Turner, "Time Sliced Optical Burst Switching," *IEEE INFOCOM*, 2003, pp. 2030-2038.

[10] S. Sheeshia and C. Qiao, "Synchronous Optical Burst Switching," *BROADNETS*, 2004, pp. 4-13.

[11] Z. Zhang et al., "Slotted Optical Burst Switching (SOBS) Networks," *NCA*, 2006, pp. 111-117.

[12] J. Liu and N. Ansari, "Impact of the Burst Assembly Interval on the OBS Ingress Traffic Characteristics and System Performance," *ICC*, 2004, pp. 1559-1563.

[13] V.M. Vokkarane, K. Haridoss, and J.P. Jue, "Threshold-Based Burst Assembly Policies for QoS Support in Optical Burst-Switched Networks," *SPIE OptiComm*, 2002, pp. 125-136.

[14] T. Tachibana, T. Ajima, and S. Kasahara, "Round-Robin Burst Assembly and Constant Transmission Scheduling for Optical Burst Switching Networks," *GLOBECOM*, 2003, vol. 5, pp. 2772-2776.

[15] P. Ji, Z. Ge, J. Kurose, and D. Towsley, "A Comparison of Hard-State and Soft-State Signaling Protocols," *SIGCOMM*, 2003, pp. 251-262.

[16] R. Braden, L. Zhang, S. Berson, A. Herzog, and S. Jamin, *Resource ReSerVation Protocol (RSVP) Version 1 Functional Specification*, IETF RFC 2205, 1997.

[17] M. Handley, H. Schulzrinne, E. Schooler, and J. Rosenberg, *SIP: Session Initiation Protocol*, IETF RFC 2543, Mar. 1999.

[18] S. Deering, *Host Extensions for IP Multicasting*, IETF RFC 1112, Aug. 1989.

[19] A. Rostami and S.S. Chakraborty, "On Performance of Optical Buffers with Specific Number of Circulations," *IEEE PTL,* vol. 17, no. 7, July 2005, pp. 1570-1572.

[20] F. Simonot, Y.Q. Song, and J.P. Thomesse, "Message Sojourn

Time for TDM Schemes with Any Buffer Capacity," *IEEE Trans. Commun.*, vol. 43, no. 2/3/4, Feb./Mar./Apr. 1995, pp. 1013-1021.

[21] M.F. Neuts, J. Guo, M. Zukerman, and H. Vu, "The Waiting Time Distribution for a TDMA Model with a Finite Buffer and State Dependent Service," *IEEE Trans. Commun.,* vol. 53, no. 9, Sept. 2005, pp. 1522-1533.

[22] "The Network Simulator: NS2," http://www.isi.edu/ nsnam/ns/.

[23] T.-W. Um et al., *Soft-State Resource Reservation Mechanism in Time-Division Burst Switching Networks,* Korea patent, application number 2006-0096500, ETRI, Korean Intellectual Property Office, 2006.

Tai-Won Um received the BS degree in electronic and electrical engineering from Hong Ik University, Seoul, Korea, in 1999, and the MS and PhD degrees from the School of Engineering, Information and Communications University, Daejeon, Korea, in 2000 and 2006, respectively. He is currently a senior member of engineering staff with ETRI, Daejeon, Korea.

Jun Kyun Choi received his BS degree in electronics from Seoul National University in 1982, and the MS and PhD degrees from KAIST in 1985 and 1988, respectively. He worked for ETRI from 1986 to 1997. He is currently working as a professor with Information and Communications University, Daejeon, Korea
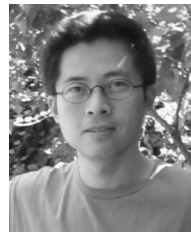
Jun Guo received the BE degree in automatic control engineering from Shanghai University of Science and Technology, Shanghai, in 1992 and the ME degree in telecommunications engineering and the PhD degree in electrical and electronic engineering from the University of Melbourne, Melbourne, in 2001 and 2006, respectively. From 2003 to 2004, he was a research associate in the Department of Electronic Engineering, City University of Hong Kong. Since 2005, he has been with the Networks Research Group, School of Computer Science and Engineering, The University of New South Wales. His research interests include multicast in wired/wireless networks.

Won Ryu received the BS degree in computer science and statistics from Pusan National University, Busan, South Korea, in 1983, and the MS degree in computer science and statistics from Seoul National University, Seoul, South Korea, in 1988. He received his PhD degree in information engineering from Sungkyunkwan University, Kyonggi, South Korea, in 2000. Since 1989, he has been a researcher with the QPS Infrastructure Technology Team, ETRI, Daejeon, Korea. He is currently a project leader.

Byung Sun Lee received the BS degree in mathematics from Sungkyunkwan University in 1980, and the MS degree in computer science from Dongkuk University in 1982. He received his PhD degree in computer science from KAIST in 2003. He is currently working as the director of the Convergence Service Platform Research Department, ETRI.