FACTA UNIVERSITATIS (NIŠ)
SER.: ELEC. ENERG. vol. 21, no. 2, August 2008, 183-194

Modelling and Performance Evaluation of Optical Burst Switched Node with Deflection Routing and Dynamic Wavelength Allocation

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Abstract: In this paper the effect of dynamic wavelength allocation (DWA) scheme implementation to the OBS node performance is investigated. We have developed the mathematical model of an OBS node in order to evaluate the burst blocking probability. It is proposed to allocate a part of total wavelength capacity to be used by deflected bursts only. The results obtained from the model show that if the number of allocated wavelengths is dynamicaly adapted to the deflected burst traffic intensity, the total blocking probability and deflected burst blocking probability significantly decrease. Concerning to the hardware requirements the implementation of deflection routing needs the limitted optical FDL buffer incorporation, to provide the deflected burst with the extra offset time. Also, control logic for burst scheduler needs to be upgraded to perform the dynamic wavelength allocation for deflected bursts.

Keywords: Wavelength division multiplexing, optical burst switching, deflection routing, burst blocking probability, just enough time signaling, dynamic wavelength allocation.

1 Introduction

THE EXPLOSIVE growth of Internet traffic is driving the demand of more and more bandwidth in the network backbone, especially since multimedia services have become the major direction of application development in recent years. With recent advances in wavelength division multiplexing (WDM) technology, the

Manuscript received on December 24, 2007.

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amount of raw bandwidth available in fiber links has increased by many orders of magnitude. Harnessing the huge bandwidth in optical fiber is essential for the development of the next generation optical Internet.

Because of the pervasive usage of the Internet Protocol (IP), it has been a crucial issue to provide a reasonable solution of Optical Internet (i.e. IP-over-WDM) which can efficiently and flexibly utilize the huge potential capacity to accommodate the exploding Internet based applications. As a matter of fact, the core of this issue lies in the design of switching paradigm. In the optical networking evolution, the most important switching techniques are: wavelength routing, optical packet switching and optical burst switching.

In recent years, a novel paradigm named optical burst switching (OBS), has been retaining advantages of above two approaches while eliminating their shortcomings as possible, [1]. The data burst consists of several IP packets may have a variable size and is transmitted through the OBS network all optically.

The burst header is sent as a control packet ahead of the data burst through the out-of-band channel in order to configure the optical switches and reserve free wavelengths along the path to a destination node. While the control packet is setting up the path, the burst is waiting in the electronic buffer for a period called offset time.

The problem arises whenever two or more bursts try to reserve the last free wavelength on the same output port. This situation causes the contention of bursts. There are several techniques that can be involved in resolving this problem, for instance deflection routing [2, 3], using the optical buffer made of finite delay line (FDL) [4], etc.

Deflection routing is invoked to save the burst of dropping and to redirect the contending burst to the alternate path, which is usually longer than the primary one. However, the problem of insufficient offset time may occur, because the offset time is calculated according to the primary route, which is as a rule the shortest one. It means that control packet needs extra offset time to configure deflection route. The FDL buffer could provide an additional delay to prevent the data burst to arrive in the node before the control packet configures the optical switch in the node and reserves the output channel. Since the optical buffer technology is still immature and has not reached the level of its counterpart electronic buffer considering the possible capacity and the current cost, we propose its limited appliance just for providing an extra offset time to the deflected burst.

In this paper we propose a novel dynamic wavelength allocation (DWA) scheme and investigate its influence to OBS node performance. In Section 2 the deflection routing and JET signaling scheme are presented. The block scheme of OBS node architecture is depicted and explained in Section 3. The development of the analytical model of the OBS node and the DWA scheme implementation are presented in Section 4. Numerical results obtained analytically are evaluated in Section 5. In Section 6 we present some concluding remarks.

2 Deflection Routing in OBS Network Based on JET Signaling

Just Enough Time (JET) is the most prevailing distributed reservation protocol for OBS networks today which does not require any kind of optical buffering or data burst delay at each intermediate node. It accomplishes this by letting each control packet to carry the offset time information and make the so called delayed reservation for the corresponding burst, i.e., the reservation starts at the expected arrival time of the burst. The bandwidth is reserved for the burst starting from the burst arrival time until it traverses to the next switch.

Another important feature of JET is that the burst length information is also carried by the control packet, which enables it to make closed-ended reservation. This closed-ended reservation helps the intermediate node make intelligent decisions as to whether it is possible to make a reservation for a new burst and thus the effective bandwidth utilization can be increased.

The process of bandwidth reservation is performed in one direction, when JET signaling scheme, is used. So, the application of JET signaling scheme does not guarantee the burst delivering on the destination, [5]. IP packets arriving in the same ingress node and having common destination are assembled into a huge burst. A header of a burst is sent as a control packet along the separate channel from the burst payload, and after the expiration of the offset time the burst is sent. During the offset time, the burst waits in electronic domain while the control packet reserves switching and transmission resources along the path.

In a conventional electronic router/switch, contention between packets can be resolved by buffering. However, in OBS networks, no or limited buffering is available and thus burst scheduling and contention resolution must be done in a different manner. If wavelength conversion capability is feasible, an incoming burst may be scheduled onto multiple wavelengths at the desired output port. A burst scheduler will choose a proper output wavelength for the burst taking into consideration the existing reservations made on each wavelength, and make a new reservation on the selected channel. Delayed reservation schemes [6], allow multiple setup messages to make future reservations on a given wavelength (provided that these reservations do not overlap in time). The output wavelength is reserved for an amount of time in proportion with the length of the burst.

Deflection routing implementation is demonstrated in the following example of the OBS network. For a source-destination node pair (S-D), let H is the number of hops between S and D along the path, and δ is the maximum processing time of the control packet at one hop. The total delay time of the control packet along the path is not longer than of $\Delta = H\delta$, so the offset time has the minimum value $T = \Delta$. In Fig. 1(a), the primary path between S and D is S-A-B-D, with $H = 3$. Each burst is preceded by a control packet for $T = 3\delta$ and the burst will arrive at D just after the control packet is processed. If the control packet had not succeeded to reserve required bandwidth at one of predetermined hops, (e.g. on hop B-D), the control packet would not reach D, as in Fig. 1(b). As a consequence, the burst arriving in B will be dropped, as in Fig. 1(c).

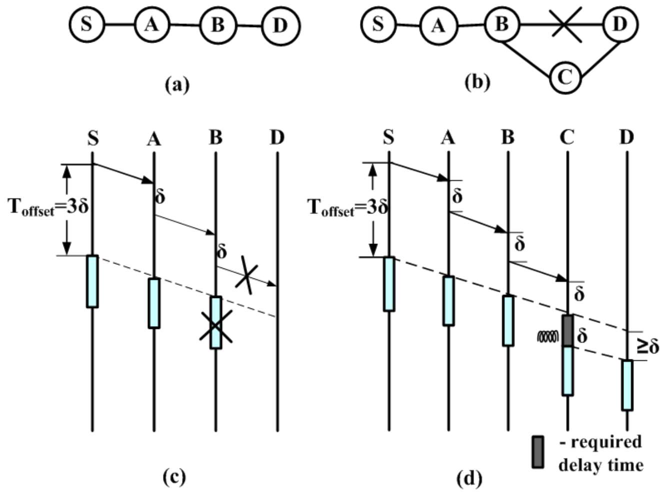

Fig. 1. Possible cases of the burst transmission from S to D: (a) network sample, (b) congestion at node B, (c) unsuccessful transmission on path S-A-B-D, congestion at B, (d) deflection routing involved in B, extra offset time provided in C.

In order to decrease the blocking probability in the OBS network, the deflection routing can be invoked at the congested hop. The deflection route between the congested node B and destination D is B-C-D, so the burst will be rerouted from B over C to D, as in Fig. 1(d).

In addition, when we consider deflection routing in an OBS network, the offset time for the primary path might not be enough for a longer deflected path. In that case, an extra offset time has to be added for the deflected burst.

Let h be a number of extra hops added to the primary route due to the deflection. If the initial offset time is $T = H\delta$ and $h > 0$, then the deflected burst will pass H hops of the path and reach C before the bandwidth between C and D is reserved. In order to prevent burst from dropping, it is necessary to provide the extra offset delay of $h\delta$ time units. During the extra offset time the control packet could manage to reserve a bandwidth on path from C to D. Fig. 1(d) shows that the deflection route

B-C-D contains one more hop than the original route B-D, i.e. $h = 1$.

We consider that the arriving burst shall be delayed for an extra offset time in the FDL buffer of switch C next to the congested switch B. It will provide enough time for control packet to set up the optical path for the arriving burst.

3 An OBS Node Architecture

Originally the OBS node is planned to be a system without memory, so the data burst cuts through it transparently. On the contrary, the control packet goes through the O/E/O conversion in each intermediate OBS node on the route.

The OBS node consists of two functional units, [7]: control and switching units, as it is depicted in Fig. 2. Control unit processes the control packet containing the information about the routing and the burst length, and generates the control signals that manage the processes in the switching unit.

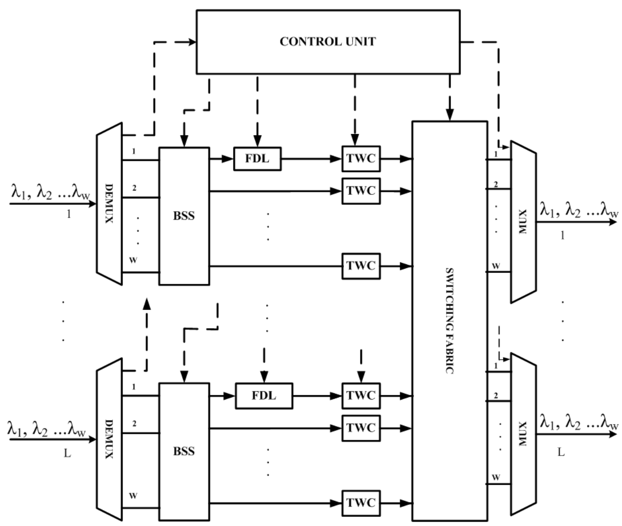

Fig. 2. The optical burst switched node architecture.

Control unit performs the selection of the output link wavelengths and closes the appropriate semiconductor optical amplifier (SOA) gates of the broadband-and-select switch (BSS). The arriving burst wavelength is converted by the tunable wavelength converter (TWC) to an available output link wavelength. Besides, the control unit schedules the time delay intervals in the FDL buffers for deflected bursts, according to the entries in the lookup table.

Switching unit cross-connects each switching fabric input wavelength to the appropriate output wavelength, without possibility of wavelength conversion.

4 Analytical Model of OBS Node with Deflection Routing and DWA Scheme

We have already mentioned that deflection routing can be invoked in case of contention. In this paper we propose a novel procedure called *Dynamic Wavelength Allocation (DWA) scheme,* in which k of W wavelengths on each output link are allocated to the deflected bursts only, hoping that its implementation will decrease the possibility of multiple deflection, because this phenomenon may cause higher traffic intensity and network congestion. Number k is determined dynamically in compliance with the deflected burst traffic intensity.

In order to evaluate the impact of the DWA scheme on the OBS node performance, we have developed the analytical model of an OBS node with deflection routing and DWA scheme. We have investigated the operation of DWA scheme in conjunction with deflection routing performed in OBS node whenever the contention among the bursts occurs, and estimated the average burst blocking probability as a measure of OBS node performance.

In this model we assume that:

- There are W wavelengths on each output optical fiber link, represented by a set $\Lambda = \{\lambda_1, \lambda_2, \ldots, \lambda_w\}$
- There are k of W wavelengths, allocated to the deflected bursts;
- The burst length is exponentially distributed with mean $L = 1/\mu$;
- The average number of extra hops for the deflected burst is h;
- The maximum processing time for the control packet at each hop is δ;
- The burst arrival at a given output port of an OBS node is a Poisson process with a mean rate γ_1 for non-deflected and γ_2 for deflected bursts;
- The equivalent offered load is $a = a_1 + a_2$, where non-deflected burst traffic load is $a_1 = \gamma_1/\mu$ and deflected burst traffic load is $a_2 = \gamma_2/\mu$.

Each input of the OBS node is equipped with one FDL, made of an optical fiber, where W bursts may be simultaneously delayed for certain extra offset time.

In order to estimate blocking probability we use a Markovian $M/M/c/c$ queuing model to construct a two-stage model of OBS node [8], shown in Fig. 3. In accordance to DWA scheme, the first stage represents k wavelengths of the output fiber link allocated to the deflected bursts only. The second stage represents the remaining number of wavelengths $(W-k)$ on the output link, shared by both non-deflected and the deflected bursts rejected from I stage.

As determined in DWA scheme, the k wavelengths on the output fiber are exclusively allocated to the deflected bursts in order to avoid their subjection to multiple

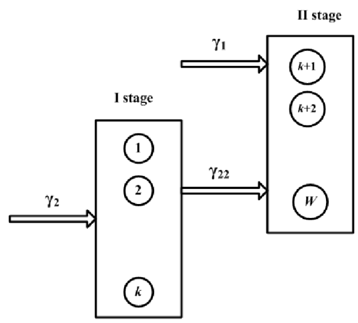

Fig. 3. Two-stage model of OBS node.

deflections and to decrease the deflected burst blocking probability.

The first stage in Fig. 3, represents the $M/M/k/k$ loss model, in which probability (B_I) that k wavelengths are busy is given by Erlang's loss formula:

$$B_I = \frac{\frac{a_2^k}{k!}}{\sum\limits_{i=0}^{k} \frac{a_2^i}{i!}}, \tag{1}$$

a_2 is the traffic load in the I stage. This expression for the probability relates to all types of traffic that can be modeled with Poisson arriving process and with anyone processing time, in this case anyone distribution of the burst length (for instance exponential, Pareto, etc.).

The deflected bursts blocked in I stage are not discarded, but they are rerouted to the II stage with a mean rate γ_{22}, given by:

$$\gamma_{22} = \gamma_2 \cdot B_I. \tag{2}$$

The II stage represents the multi-dimensional traffic model, defined in [9], since the transmission resources are shared by the bursts with different features. It is assumed that the non-deflected and deflected burst arrivals are the Poisson processes with mean rates γ_1 and γ_{22}, respectively. The state transition diagram, of the multi-dimensional model is shown in Fig. 4, and we find that the *number of steady states (nos)* is:

$$nos = \frac{(W-k+1)(W-k+2)}{2} \tag{3}$$

Let p_{ij} denotes the joint probability that i non-deflected and j deflected bursts exist in the steady state. In Fig. 4, each state is identified by notation (i, j), where $0 \le i \le (W-k)$, $0 \le j \le (W-k)$, $0 \le (i+j) \le (W-k)$.

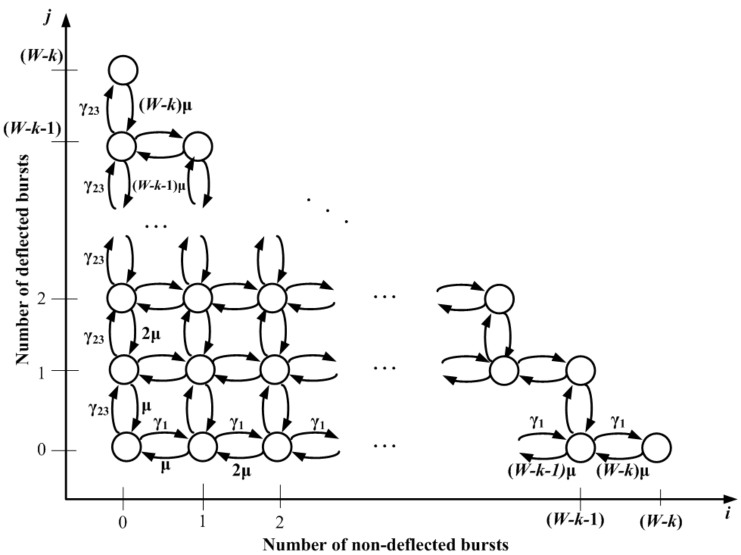

Fig. 4. State transition diagram of multi-dimensional model.

Then, according to Fig. 4, we get a system of steady state equations,

$$[\gamma_1 + \gamma_{22} + (i+j)\mu]\, p_{ij} = \gamma_1 p_{i-1,j} + \gamma_{22} p_{i,j-1} + (i+1)\,\mu\, p_{i+1,j} + (j+1)\,\mu\, p_{i,j+1}, \tag{4}$$

for $0 \le i \le W-k-1$, $0 \le j \le W-k-1$, $0 \le i+j \le W-k-1$,
and

$$(i+j)\,\mu\, p_{ij} = \gamma_1 p_{i-1,j} + \gamma_{22} p_{i,j-1}, \tag{5}$$

for $0 \le i \le W-k$, $j \le W-k-i$.

Probability is $p_{ij} = 0$, for $i, j < 0$.

Denoting the individual non-deflected and deflected burst traffic load by $a_1 = \gamma_1/\mu$ and $a_{22} = \gamma_{22}/\mu$ it can be shown that the product form solution p_{ij} from (4) and (5) is:

$$p_{ij} = \frac{a_1^i}{i!}\frac{a_{22}^j}{j!}\, p_{00}. \tag{6}$$

From normalization condition, p_{00} is determined as:

$$p_{00} = \left[\sum_{i=0}^{(W-k)} \sum_{j=0}^{(W-k-i)} \frac{a_1^i}{i!}\frac{a_{22}^j}{j!}\right]^{-1}. \tag{7}$$

According to the transition rules defined in Fig. 4, and using (7), the second stage blocking probability (B_{II}) may be expressed as:

$$B_{II} = \sum_{i=0}^{W-k} \frac{a_1^i}{i!} \frac{a_{22}^{(W-k-i)}}{(W-k-i)!} p_{00}. \tag{8}$$

Then, the solution for an average II stage non-deflected burst blocking probability (B_{IInd}) and deflected burst blocking probability (B_{IId}), may be written as:

$$B_{IInd} = \frac{a_1 B_{II}}{a_2}, \qquad B_{IId} = \frac{a_{22} B_{II}}{a_2}, \tag{9}$$

where $a_2 = a_1 + a_{22}$ is the total offered load to the II stage.

The average burst blocking probability (B) for the two-stage model, according to the definition in [9] and from (9), finally results in:

$$B = \frac{a_1 B_{IInd} + a_2 B_I B_{IId}}{a}. \tag{10}$$

Separating in (10) the average non-deflected burst blocking probability (B_{nd}) and the average deflected burst blocking probability (B_d), it follows that:

$$B_{nd} = \frac{a_1 B_{IInd}}{a}, \qquad B_d = \frac{a_2 B_I B_{IId}}{a}. \tag{11}$$

5 Numerical results

We had investigated an effect of k to the overall burst blocking probability (B) and deflected burst blocking probability (B_d), by changing a portion of deflected burst traffic in total traffic load (a). The calculations were executed for the several different input values of deflected burst traffic intensity, i.e. for $a_2 = 0.3a$, $0.4a$, $0.5a$, $0.6a$ and $0.7a$. The total offered load is normalized with the number of wavelengths ($m = a/W$), and the value m is in the range [0.1,1]. The number of the output link wavelengths is $W = 64$, and k is dynamically changed in the range [0,32]. The numerical results are obtained for the average deflected burst blocking probability B_d, non-deflected burst blocking probability B_{nd} and the overall burst blocking probability B, for all possible values a_2 and k.

We have figured out that the minimum value of the burst blocking probability obtained for different values k depends on the deflected burst traffic intensity a_2. For each value of deflected burst traffic intensity the value k_{opt} corresponds to the minimum value of the burst blocking probability (B) as it is presented in Table 1.

Table 1. Analytical results for k_{opt}.

a_2	$0.3a$	$0.4a$	$0.5a$	$0.6a$	$0.7a$
k_{opt}	8	11	16	25	32

It is evident that if the deflected burst traffic increases the value k_{opt} grows larger, too.

Different curves for the minimal burst blocking probabilities (B) are obtained for the various values a_2 and k_{opt}, and are depicted in Fig.5. They are compared to B, when $k = 0$. We have figured out that if the deflected burst traffic (a_2) increases, the value k_{opt} continues to enlarge. The values on the x axis in Fig. 5, are increased by one order of magnitude comparing to m (x =10m).

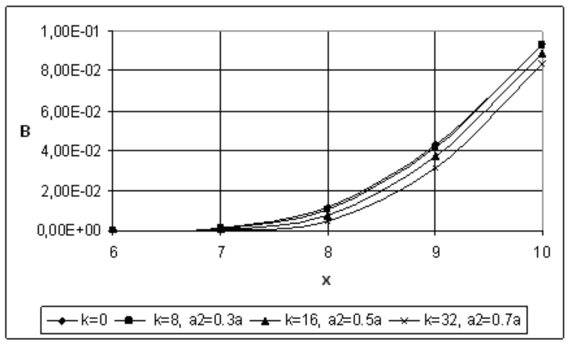

Fig. 5. Burst blocking probability B in function of the offered traffic load a, and different values for a_2 and k_{opt}.

The distinguished curves of burst blocking probabilities B_d and B for high traffic $a_2 = 0.7a$ and $k = 0$ and 32, are depicted in Fig. 6. It can be seen that B_d and B have been significantly decreased in comparison to the same curves in case when DWA scheme is not implemented, i.e. when $k = 0$. The improvement of B is more evident for the greater values of traffic intensity and is in the range [0, 100], but for the values B_d are even in the range [0, 300]. The improvement of B is achieved by two and for B_d by three orders of magnitude.

The OBS node blocking performance is upgraded if k is adapted to the deflected burst traffic intensity.

All various combinations of a_2, k and m produce the strings of numerous values of B_d, B_{nd} and B, but in this paper we presented just the distinctive examples of them. Obtained results indicate the benefit from DWA scheme implementation in the OBS node with deflection routing. That is the reason why we suggest the usage of this scheme as it can improve OBS node performance.

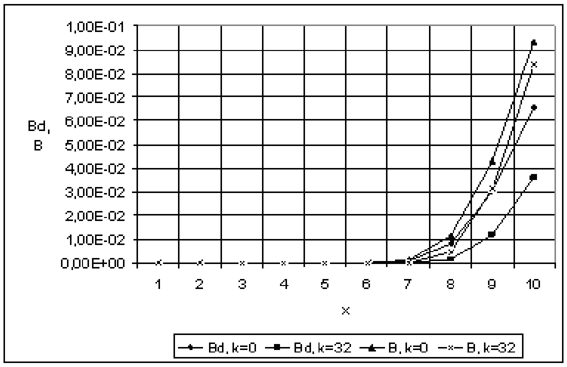

Fig. 6. The comparison of blocking probabilities B_d to B for $k = 0$ and $k = 32$.

6 Conclusion

Modelling an optical burst switched node and generating the offered load, have shown the impact of DWA scheme implementation in conjunction with deflection routing to the OBS node performance. It is proved that they significantly decrease the both, overall burst blocking probability and the deflected burst blocking probability. The implementation of DWA scheme in conjunction with deflection routing yields the improvement of the OBS node performance.

Concerning to the hardware requirements the implementation of deflection routing needs the limitted optical FDL buffer incorporation in OBS node, to provide the deflected burst with the extra offset time.

Also, control logic for burst scheduler needs to be upgraded to perform the dynamic wavelength allocation for deflected bursts.

References

[1] Y. Chen, C. Quiao, and X. Yu, "Optical burst switching (OBS): A new area in optical networking research," *IEEE Network*, vol. 18, no. 3, pp. 16–23, May/June 2004.

[2] C.-H. Hsu, T.-L. Liu, and N.-F. Huang, "Performance analysis of deflection routing in optical burst-switched networks," in *Proc. of IEEE INFOCOM*, New York, June 2002.

[3] Y. Chen, H. Wu, D. Xu, and C. Qiao, "Performance analysis of optical burst switched node with deflection routing," in *Proc. on International Conference on Communications -ICC*, 2003, pp. 1355–1359.

[4] C. Gauger, "Dimensioning of FDL buffers for optical burst switching nodes," in *Proc. of Optical Network Design and Modeling (ONDM 2002)*, Torino, Italy, 2002.

[5] A. Myers and P. Bayvel, "Performance of the just-enough-time (JET) scheme for optical burst switching," in *Proc. of London Communications Symposium (LCS2001)*, Sept. 2001, pp. 163–166.

[6] C. Qiao and M. Yoo, “Choices, features and issues in optical burst switching,” *Optical Networks Magazine*, vol. 1, no. 2, pp. 36–44, 2000.

[7] Y. Xiong, M. Vandenhoute, and H. Cankaya, “Control architecture in optical burst-switched WDM networks,” *IEEE Journal on Selected Areas in Communications*, vol. 18, pp. 1838–1851, Oct. 2000.

[8] D. Gross and C. Harris, *Fundamentals of Queueing Theory*. New York: John Wiley& Sons, 1974.

[9] H. Akimaru and K. Kawashima, *Teletraffic: Theory and Applications*. Berlin, Germany: Springer-Verlag, 1993.