ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2008. No. 3(83)
ELEKTRONIKA IR ELEKTROTECHNIKA

T180 TELECOMMUNICATIONS ENGINEERING
TELEKOMUNIKACIJŲ INŽINERIJA

An Approach to Resolving Contention Problem in an Optical Burst Switching WDM Network

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Introduction

The rapid growth of Internet traffic demands high transmission rates that only can provide optical networks with wavelength division multiplexing (WDM) technology.

In order to provide optical switching for next generation Internet traffic in a flexible way, a new switching paradigm, called optical burst switching (OBS), is proposed [1] for using in WDM optical networks.

In an OBS node, bursts of data consisting of multiple packets are switched totally optically through the node. A control packet is transmitted ahead of the burst for a certain time, called *offset time*. Offset time has to be as long as to let the control packet to configure the switches and reserve transmission resources along the burst's route. The data burst follows the control packet after the offset time without waiting for an acknowledgment that the path is set. This reservation process, known as Just-Enough-Time signaling scheme [2] is considered in this paper.

A major concern in OBS network is a contention that occurs in OBS node whenever the multiple bursts try to leave the switch from the same output port when the only one wavelength is available. The deflection routing and optical buffering is commonly used to resolve contention in OBS network [3].

Since the *offset time* is calculated according to the shortest primary route, the problem of insufficient offset time arises when the burst is deflected to the usually longer deflection route. As a consequence of insufficient offset time the deflected burst could arrive in the OBS node before the optical switch is configured and bandwidth is reserved for its transmission. One way to provide an *extra offset time* for deflected burst is to use limited optical buffering [4].

To reduce burst losses induced by contention in OBS network, we propose an implementation of a new *wavelength allocation (*WA*) scheme* in conjunction with the deflection routing in the OBS node. In the WA scheme a certain number of wavelengths on the output fiber link are allocated to the deflected bursts exclusively, in order to reduce the overall congestion and improve the network utilization.

Applying Deflection Routing to the OBS Network Based on JET Signaling

The process of bandwidth reservation for the data burst is performed in one direction when JET signaling scheme is used. A header of the burst is sent as a control packet along the separate path 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 buffer of the edge network node. The control packet employs the delayed reservation (DR) technique [4].

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 $\Delta = H \cdot \delta$, 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 $H=3$. If $T = 3 \cdot \delta$, 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, Fig. 1(b). As a consequence, the burst arriving in B will be dropped, as in Fig. 1(c).

In order to improve the blocking probability in the OBS network, the deflection routing can be involved 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, Fig. 1(d).

As the deflection route is commonly longer than primary one, the initial offset time is not enough for reservation process, so it is necessary to provide certain extra offset time for 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 $T=H\cdot\delta$ 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 $h\cdot\delta$ 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.

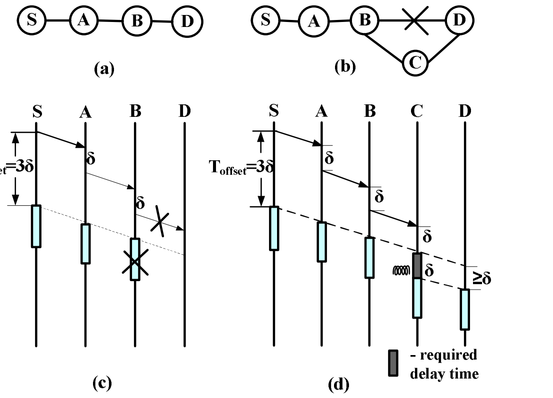

Fig. 1. Possible cases of the burst transmission from S to D: (a) network sample, (b) congestion at node B, (c) unsuccessful transmission on path S-A-B-D, congestion at B, (d) deflection routing involved in B, extra offset time provided in C

A few different proposals for solving this problem are explained in [4], but we will consider that the arriving burst will be delayed for the extra offset time in the FDL buffer of the switch next to the congested switch (node C).

The Optical Node Architecture

We propose the optical node architecture similar as in [5], in which we equipped each input with a single optical finite delay line (FDL) buffer which can provide an extra offset time for deflected bursts only.

Fig. 2 displays the OBS node structure consisting of the control and switching units. The control unit processes the control packet containing the information about routing and burst length and generates the signals for managing the processes in the switching unit.

The control packet goes through the O/E/O conversion at each intermediate node while the burst payload traverses along the path completely in optical domain.

Each input has one FDL buffer that can delay W deflected bursts simultaneously. A tunable wavelength converter (TWC) is used to convert the arriving burst wavelength to any other wavelength available at the output link. The switching fabric performs switching from any input to any output.

The control unit operates the wavelength selection at the output link, closing the selected semiconductor optical amplifier gates (SOA). Besides, the control unit schedules the time delaying intervals in the FDL buffers for deflected bursts, according to the entries in the lookup table.

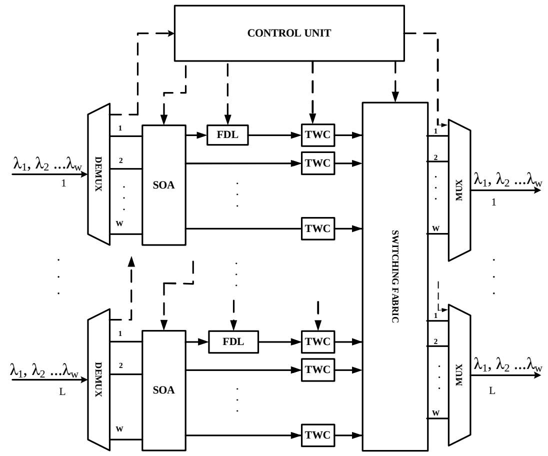

Fig. 2. The optical node architecture

We propose the allocation k of W wavelengths on the each output link to be used by deflected bursts only, in order to decrease the possibility of repeating the deflection of already deflected bursts. This procedure is called *Wavelength Allocation (WA) scheme.*

The Analytical Model of an OBS Node

In order to estimate the blocking performance we investigate the operation of the *WA scheme* in conjunction with deflection routing performed in OBS node whenever the contention among the bursts occurs.

We assume that:

- There are W wavelengths on each output optical fiber link, represented by a set $\Lambda=\{\lambda_1, \lambda_2, \ldots \lambda_w\}$;
- 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;
- There are W wavelengths in the FDL buffer, an average extra offset time for deflected bursts, that is equal $1/\mu_d\cdot\delta$;
- The burst arrival at a given output port of an OBS node is a Poisson process with a mean rate of γ_1 for non-deflected and γ_2 for deflected bursts;
- The equivalent offered load is $A=a_1+a_2$, where $a_1=\gamma_1/\mu$ is non-deflected burst traffic load and $a_2=\gamma_2/\mu$ is deflected burst traffic load.

We propose the use of a Markovian *M/M/c/c* queueing model to construct a three-stage model of OBS node, shown in Fig. 3. The first stage represents the FDL buffer that provides an *extra offset time* for deflected bursts. The second and third stages represent W wavelengths of the output link. In accordance with the *WA scheme*, the second stage represents k wavelengths on the output fiber link allocated to the deflected bursts only. The third stage represents the remaining number of wavelengths on the output link (W-k), shared by both non-deflected bursts and the deflected bursts rejected from the second stage.

The first stage is represented by the *M/M/W/W* loss model. The blocking probability (B_1) of FDL buffer can be calculated from Erlang's loss formula [6].

According to the properties of the Markovian model the departure time distribution is identical to the arrival time distribution (if there is no restriction on the system capacity i.e., *M/M/c/∞* model). So, the departure from the first stage is the Poisson process with mean rate γ_{22}, given by:

$$\gamma_{22} = (1 - B_1) \cdot \gamma_2. \quad (1)$$

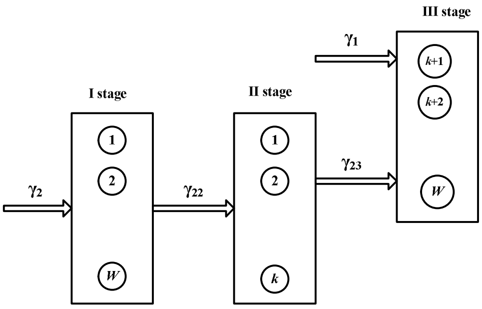

Fig. 3. Three-stage model of OBS node

The second stage represents, as defined in the *WA scheme*, the *k* wavelengths on the output fiber exclusively allocated to the deflected bursts. This stage represents the *M/M/k/k* loss model in which probability (B_2) that *k* wavelengths are busy is given by Erlang's loss formula [6].

The deflected bursts blocked in the second stage are not discarded, but they are routed to the third stage with a mean rate γ_{23}, given by:

$$\gamma_{23} = B_2 \cdot \gamma_{22}. \quad (2)$$

The third stage represents the multi-dimensional traffic model, since the transmission resources are shared by the bursts with different characteristics. It is assumed that the non-deflected and deflected burst arrivals are the Poisson processes with mean rates γ_1 and γ_{23}.

According to the state transition diagram for the multi-dimensional model shown in [6], p_{ij} denotes the joint probability that *i* non-deflected and *j* deflected bursts exist in the steady state. Then, we get a system of steady state equations:

$$[\gamma_1 + \gamma_{23} + (i+j)\mu]p_{ij} = \gamma_1 p_{i-1,j} + \gamma_{23} p_{i,j-1} + \\ + (i+1)\mu p_{i+1,j} + (j+1)\mu p_{i,j+1}, \quad (3)$$

where $0 \le i \le W - k - 1$, $0 \le j \le W - k - 1$, $0 \le i + j \le W - k - 1$.

$$(i+j)\mu p_{ij} = \gamma_1 p_{i-1,j} + \gamma_{23} p_{i,j-1}, \quad (4)$$

where $0 \le i \le W - k$, $j \le W - k - i$, p_{ij}=0 for i,j<0.

Denoting the individual non-deflected and deflected burst traffic load by $a_1 = \gamma_1/\mu$ and $a_{23} = \gamma_{23}/\mu$ it can be shown that the product form solution p_{ij} is:

$$p_{ij} = \frac{a_1^i}{i!} \cdot \frac{a_{23}^j}{j!} \cdot p_{00}. \quad (5)$$

According to the transition rules defined in [6], and using (5), the third stage blocking probability B_3 is expressed as:

$$B_3 = \sum_{i=0}^{W-k} \frac{a_1^i}{i!} \cdot \frac{a_{23}^{(W-k-i)}}{(W-k-i)!} p_{00.} \quad (6)$$

Then, the solution for average third stage non-deflected burst blocking probability (B_{3nd}) and blocking probability (B_{3d}) for deflected bursts, may be written as:

$$B_{3nd} = \frac{a_1 B_3}{a_3}, \qquad B_{3d} = \frac{a_{23} B_3}{a_3}, \quad (7)$$

where $a_3 = a_1 + a_{23}$ is the total offered load to the third stage.

The average burst blocking probability (*B*) for the three-stage model, according to the definition in [6] and from (7), finally results in:

$$B = \frac{a_1 B_{3nd} + a_2 \left[B_1 + (1 - B_1) \cdot B_2 B_{3d} \right]}{A}. \quad (8)$$

Separating non-deflected burst blocking probability (B_{nd}) and the average deflected burst blocking probability (B_d) in (8) follows that:

$$B_{nd} = \frac{a_1 \cdot B_{3nd}}{A}, \qquad B_d = \frac{a_2 \left[B_1 + (1 - B_1) \cdot B_2 B_{3d} \right]}{A}. \quad (9)$$

Analytical results obtained for the deflected burst blocking probability (B_d) as a function of traffic load normalized per wavelength $\beta = A/W$, when a_1=0.7*A*, a_2=0.3*A*, $L = 1/\mu$=48μs, *h*=2, δ=0.1*L*, $1/\mu_d$=0.2*L*, *W*=16, *k*=0, 2, 4, 6, respectively, are depicted in Fig. 4.

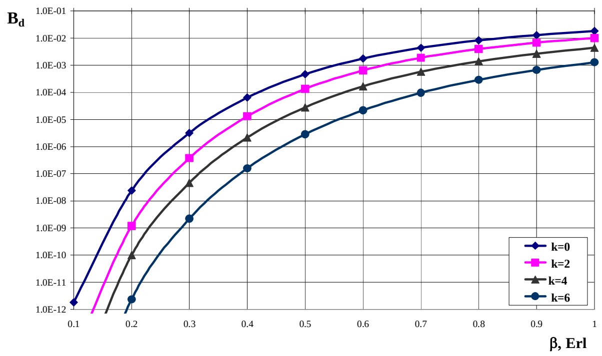

Fig. 4. Deflected burst blocking probability B_d versus traffic load β (Erl), for k=0,2,4,6

The analytical results indicate that the deflected burst blocking probability (B_d) generally decreases while *k* increases. This is because of the greater part of the total capacity of the output link can be used by the deflected burst.

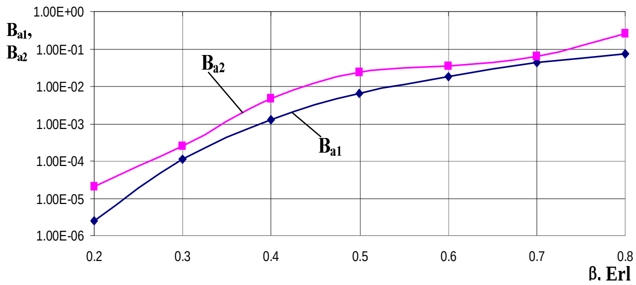

Fig. 5. Average burst blocking probabilities B_{a1} and B_{a2} versus traffic load β (Erl)

For instance, the improvement of the deflected burst blocking probability (B_d) value when *k*=6 can be more than one order of magnitude in comparison with B_d when *k*=0, for the heavy load β=1. Moreover, B_d is 1000 times lower when *k*=6 than when *k*=0 for the low offered traffic β=0.2.

In Fig. 5 are shown the estimated values of total blocking probability (B_{a1}) obtained in our model compared to B_{a2} obtained in [4], where FDL buffers had been used by both non-deflected and deflected bursts. The significant performance improvement for the burst blocking probability is achieved in case when *WA scheme* has been implemented.

Simulation model of an OBS node

The simulation model has been developed for an OBS node using object oriented simulation software tool Delsi for Delfi 4.0, as in [7].

The *WA scheme* was applied to three-stage model of OBS node, and traffic load is generated according to the same input parameters as in the analytical model.

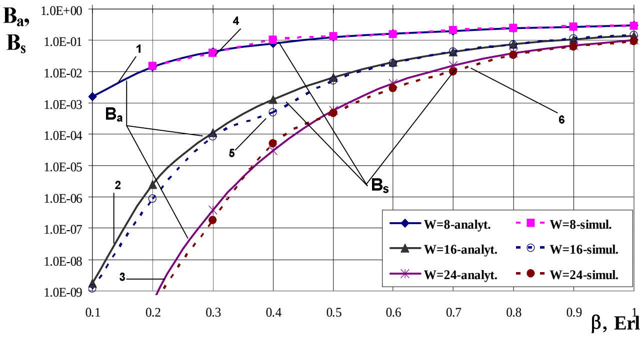

Fig. 6. Burst blocking probability B_a analyticaly obtained and B_s obtained by simulation versus traffic load β (Erl) for the wavelength number W=8, 16, 24 and the number of allocated wavelengths k=4

The simulation experiments were executed with six million generated bursts entering the OBS node. The duration of simulation experiment depended on the input traffic intensity.

Simulation executions had taken more time for low than for heavy traffic load.

We have measured the burst blocking probability for deflected and non-deflected bursts, and the obtained results were compared with the analytical results.

Simulation models are based on the three-stage model of OBS node. Solid lines B_a, and dotted lines Bs, in Fig. 6, depict the obtained analytical results compared to simulation results for the average burst blocking probability, when k=4 and W=8, 16 and 24.

Conclusions

Applying the simple *WA scheme* in the OBS network reduces the effect of multiple deflection paths on the network throughput, protecting the burst to be subjected to multiple deflections and simplifying the hardware implementation. The simplification of hardware is reflected in the fact that FDL buffers have to be provided only for deflected bursts. It also contributes to the cost reduction, because the FDL buffers are still rather expensive.

As the number of wavelengths on the fiber link increases from day to day, the reservation of k wavelengths for the usage of deflected bursts only, will not affect the non-deflected burst blocking probability performance significantly.

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Submitted for publication 2007 12 12

R. Bojović, D. Pevac, I. Petrović. An Approach to Resolving Contention Problem in an Optical Burst Switching WDM Network // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 3(83). – P. 33–36.

We propose to use a new wavelength allocation (WA) scheme with deflection routing, whilst investigating its influence to the optical burst switching (OBS) node performance. To evaluate the burst blocking probability we have developed the analytical and simulation models of an OBS node performing WA scheme in conjunction with the deflection routing. The results obtained from the analytical and simulation models indicate that the WA scheme yields to decrease the deflected burst blocking probability and reduces the cost of OBS node in WDM optical network. Ill. 6, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

Р. Боевич, Д. Певац, И. Петрович. Распределение ресурсов в оптических WDM сетях // Электроника и электротехника. – Каунас: Технология, 2008. – № 3(83). – С. 33–36.

Предлагается новый метод распределения длины волны (WA), тем самым исследуя его влияние на эффективность узла OBS в оптических сетях. Для исследования вероятности блокировки, разработаны аналитические модели и модели моделирования узла OBS, выполняющего операцию WA. Полученные результаты показывают, что WA метод позволяет уменьшить вероятность блокировки и тем самым уменьшают цену узла OBS в оптических сетях. Ил. 6, библ. 7 (на английском языке; рефераты на литовском, английском и русском яз.).

R. Bojović, D. Pevac, I. Petrović. Išteklių pasidalijimo optiniuose WDM tinkluose problemos sprendimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. –Nr. 3(83).– P. 33–36.

Siūloma naudoti naują bangos ilgių paskirstymo (WA) nukreipiamuoju maršrutizavimu metodą, analizuojama jo įtaka optinio tinklo OBS mazgo našumui. Srauto blokavimo tikimybei apskaičiuoti sukurtas analitinis ir imitacinis OBS mazgo veikimo modelis, kuriame panaudotas WA metodas, pagrįstas nukreipiamuoju maršrutizavimu. Gauti rezultatai rodo, jog WA metodas leidžia sumažinti blokavimo tikimybę ir atpigina WDM optinio tinklo OBS mazgą. Il. 6, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).