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The Contention Resolution in OBS Network

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[1]***Abstract*—Burst contention occurs when attempting to transmit several optical bursts at the time into the same core router output port. This is a shortcoming of the Optical Burst Switching (OBS) networks and for this reason it has been challenging to implement the OBS mode into the transport networks so far. This problem can be solved applying various contention resolution strategies at core nodes (fiber delay lines, wavelength conversion or deflection routing). The following question arises: how does data transmission through the OBS network quality depend on using such strategy combination in the core node? For these reasons an analytical model has been created to find out what impact a joint application of various contention resolution strategies has on the data transmission quality. An algorithm has been proposed for the burst service in the OBS core router when a contention arises. The authors suggest applying burst segmentation only for the lower priority bursts, reducing the lower priority data losses in the case of mixed priority burst incoming flow. Every additional burst collision resolution strategy increases the time spent at the node however, so it is highly important to determine by means of simulations the optimal amount of resources needed at the core node.**

***Index Terms*—Analytical models, burst switching, optical wavelength conversion, scheduling algorithms, wavelength routing.**

I. INTRODUCTION

Optical bursts are transmitted directly through the bufferless optical wavelength division multiplexing (WDM) network, with exception of using of buffers in the network edge routers [1]. Bursts contention occurs when attempting to transmit several optical bursts at the time in to the same core router output port, i.e. when more than one burst demands the same wavelength. In such a case the core node has to make certain decisions about processing of the contending bursts. This is a shortcoming of Optical Burst Switching (OBS) networks and for this reason it has been challenging to implement OBS mode into transport networks so far. Burst contentions at the core node are inevitable because of the unpredictable nature of the burst flow. This results in low connection usability and high burst loss rate respectively. Even an occasional burst loss may have a negative impact to the quality of service. This is especially true when burst flow represents the data of real time services. Outcome may be bad if the burst lost contains the information assigned to the TCP transport. For this reason the burst contention control remains the main problem in OBS networks [2].

Bursts can be lost at a single or few OBS network core nodes in the case of contention, even when network is low loaded because of the lack of one way signalling adaptation and general scheduling [1], [3]–[6]. One can solve this problem in changing configuration parameters of edge and core routers, for example the burst length or interval of bursts assembly and bursts scheduling. The burst assembly duration at the edge routers has the main impact for the OBS core routers because of the increase of end-to-end packets transmission delay and loss [4]. Another approach for minimizing burst loss was suggested to optimize the two variables, i.e. the length and the time of bursts injected into the OBS network. An algorithm proposed explicitly reveals how burst contention resolution and congestion control must interact [5]. The new solutions are proposed for bursts scheduling – BFVF (Best-Fit Void-Filing) [6] and BORA (Burst Overlap Reduction Algorithm) [7]. BFVF assures less burst loss as well as more effective usability of empty common channel spaces because that it performs the grouping of input data by their length.

The problem of burst loss in optical burst switching (OBS) networks was suggested to be solved by gathering wavelength usability statistics and assigning specific wavelengths for some bursts according to their predetermined priorities. This method can be used only in OBS without converters [1].

It is suggested to use burst flow control for contention reduction also [8]. The Leaky Bucket Deflection method executed by OBS edge nodes permits to control flow rate. The resource reservation protocols JIT, JET, Horizon have influence on burst loss also because of collision occurrences. The use of one-way resource reservation protocols, such as JET, in OBS network means that the bursts are sent without any prior reservation path. Thus the collision occurs in bursts core router. Therefore, bursts scheduling and contention resolution are closely related, since the proper bursts scheduling algorithm can help reduce collisions. Burst loss in the three node connection is assessed depending on the OBS network resource reservation protocol selected. It was found that the JIT protocol provided a lower loss rate comparing with the JET and Horizon [8]. TCP decoupling approach was proposed for OBS congestion control which can control burst sending. It allowed reducing burst loss due to overload and more effective utilization of the connection as well [9]. It is possible to reduce burst loss ratio effectively

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adopting certain contention resolution passive strategies in the core routers. A number of comprehensive reviews of different contention resolution techniques for optical burst switched network have been presented [1], [10], [11].

II. BURST CONTENTION RESOLUTION STRATEGIES

One of the contention resolution strategies applied in core router is the wavelength conversion. It makes it possible to transmit an optical burst from node input port to any output port. Most of the effective planning algorithms offer wavelength conversion. Although this technology is not cost-effective, but it gives the network more flexibility and several useful solutions that are needed to reduce bursts losses in a router [1], [2], [4].

Fiber delay lines (FDL) is another solution for contention resolution in OBS when bursts are delayed in core routers because of the lack of random access memory. However, using FDL the delay time is less as compared to those cases when the bursts are lost and sent again, in the event of burst contention. FDL has a limited capacity however. Furthermore, a single FDL for each wavelength is required. FDL increases also the number of empty spaces in the output channels and bursts scheduling algorithms for single channel are therefore complex. For this reason, using only the FDL, increases the probability of burst loss ratio and delay. Unfortunately this solution it quite expensive and for this reason some scheduling approaches are suggested to use with the basic Latest Available Unused Channel Rescheduling Algorithm (LAUC) [1].

Another possible contention resolution strategy can be deflection routing, when the optical burst switching matrix is sent to the next output port of a predetermined core router. This method can be applied in the cases of wavelength, time or space multiplexing [1]: deflection routing by time (TDM) is used in FDL technology to delay conflicting bursts; wavelength conversion is used to convert the conflicting burst to another wavelength in the same fiber, so that network flexibility increases, also deflection routing allows to redirect the conflicting burst to the output port of the next core router, and then the burst is transmitted towards the destination node in a different path.

The deflection routing is appropriate when there is no free output port in the core node, or there is no wavelength conversion or FDL possibilities. This is a cheap way considering additional equipment required to implement it. On the other hand, its implementation is quite complex, since it must be ensured that bursts in changed direction reach the destination address. The effectiveness of the method is mainly dependent on the network topology and data routing policies. The research has compared different strategies of deflection routing, namely deflection routing, reflection routing, reflection-deflection routing and multi-topology routing, for asynchronous and synchronous burst arrivals [12].

The burst segmentation is another possible solution [1], [3], [11]. In case of collisions every burst is divided into several segments and not all the burst is lost but only the few segments of its start or end parts, these segments can be deflected or transmitted. Every segment consists of one or several packets. It is possible to transmit one burst fully, but the next one can be transmitted only partially; the overlapping part of bursts is rejected. This reduces the packet loss rate in OBS network. It is suggested to evaluate burst flow correlation in multiple cross connect routes as well as to compare bursts' lengths in output and input nodes and to calculate an average byte loss probability ByLP for the whole route [13]. A Staged Reservation Scheme (SRS) was proposed to increase the throughput of core nodes and to resolve some shortages of OBS that occurred because of the burst segmentation. In this case the Burst Control Packets (BCPs) format was restructured in order to pass the constant header and BCP to ensure alignment with the higher bandwidth, as it was used in the Flow Control and Reservation (FCRB). It was suggested to use the FCRB for flow control in OBS edge nodes to decrease burst loss in the OBS network core part. This approach allows implementing simply QoS into OBS [14].

More suitable approaches compared to segmentation use deflection routing and/or FDL. The use of electronic buffers in end routers or delay lines in core allows distributing bursts in some wavelengths to decrease contention [15]. However service quality in OBS is not assured because the packets can be transmitted disorderly and packet delay increases when applying these contentions solution strategies. Consequently the transport protocol rate achieved decreases and this is unacceptable in real time services. As was mentioned FDL is expensive and the buffer length is limited, so wavelength conversion and burst segmentation could assure higher service quality for customer but these technologies aren't economical and fully developed, and there is a demand in sophisticated control for burst transmission.

As an effective way to reduce the burst loss is using several burst contention strategies in the same OBS core router, for example, it is suggested to use wavelength converters together with FDL in one core node [16] or wavelength converters with deflection routing [17]. But questions arise about the sequence of contention resolution strategies which must be applied for bursts of various priorities coming to core node. For these reasons it is proper to assess burst priority and evaluate how OBS network performance depends on this approach.

III. THE MATHEMATICAL APPROACH FOR INVESTIGATION OF CONTENTION RESOLUTION STRATEGIES APPLYING IN CORE ROUTER

It is assumed that all strategies for burst contention resolution are implemented in the OBS core router. Questions arise: how can we use these strategies jointly, and would it be beneficial? These questions may be answered by evaluating burst loss probabilities using queue models.

Suppose that the OBS core router is a system without losses and bursts can be transmitted successfully. Burst contention in core node occurs when the bursts need to use the same output wavelength simultaneously. The burst coming into the core router with a particular wavelength must be converted into the output wavelength of the required destination address.

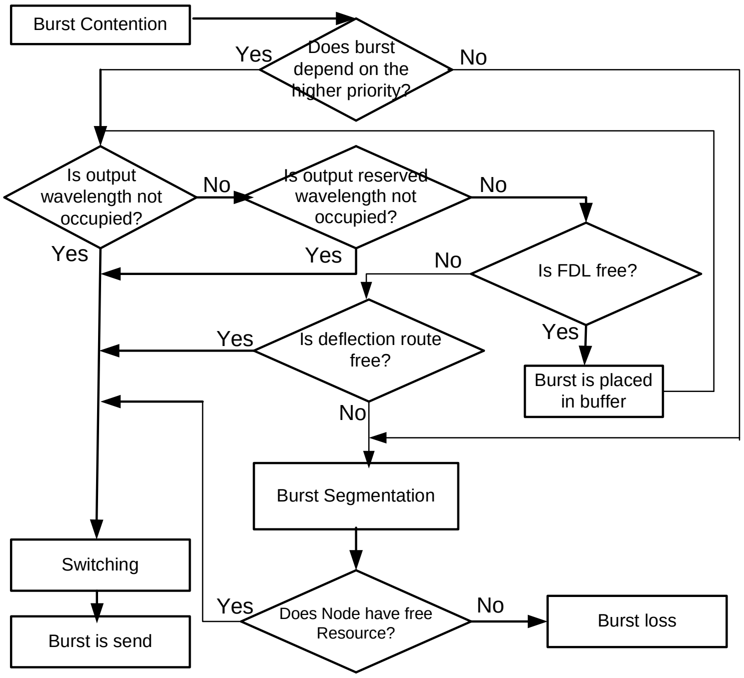

Fig. 1. An algorithm for burst service in OBS core router in case of contention. It is suggested to use additional wavelength conversion, FDL as well as deflection routing and burst segmentation.

Switching, i.e. wavelength conversion, is successful if this output channel is not occupied. The burst is sent successfully towards the required direction (Fig. 1). Otherwise, the burst is converted into the reserve wavelength and transmitted to another output of the node. When converters in the output direction are occupied the burst is placed temporarily in a buffer of the fiber delay line (FDL) and further it is transmitted into the output after some delay, i.e. converted into another wavelength. If the FDL buffer is occupied with other bursts, the incoming burst is redirected into the deflection routing output.

To decrease data loss when all the node resources are busy with other burst servicing it is useful to apply burst segmentation. This will lead to not losing of all the burst, but only its part at overlapping time (Fig. 1).

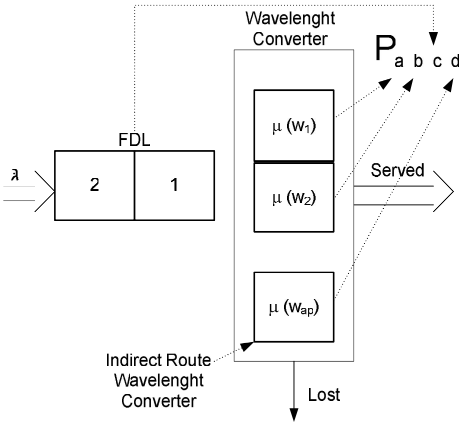

Fig. 2. A model of OBS router with FDL buffer (can hold up to two bursts), two wavelength channels and one deflection channel.

It is useful to evaluate the priority of burst containing real time service packets when contention occurs at the core router. Burst is segmented when determined that it has no priority (Fig. 1). Meanwhile the burst with higher priority earlier described it is necessary to apply earlier described collision resolution method.

Let’s take a case, when OBS router (Fig. 2) uses the following contention resolution strategies: 1) wavelength conversion for two wavelength w_1 and w_2 channels (a, b indexes), 2) FDL buffer which can hold up to two bursts (c index), 3) wavelength conversion for deflection routing over w_{ap} wavelength channel (d index).

The state graph (Fig. 3) is developed to evaluate the OBS router’s performance measures.

Each state can be described by a probability P_{abcd}: a is used to describe the wavelength w_1, b is used to describe the wavelength w_2, c is used to describe the usage of FDL, d is used to describe the usage of deflection routing over w_{ap} wavelength.

The graph (Fig. 3) has the following states:

1. 0000 – wavelengths w_1 and w_2, FDL buffer and deflection routing w_{ap} wavelength are not used;
2. 1000 – w_1 is used, w_2, FDL and w_{ap} are not used;
3. 1100 – w_1 and w_2 are used, FDL and w_{ap} are not used;
4. 0100 – w_1 is not used, w_2 is used, FDL and w_{ap} are not used;
5. 1101 – w_1 and w_2 are used, FDL is not used, w_{ap} is used;
6. 1110 – w_1 and w_2 are used, FDL buffer is used and contains one burst, w_{ap} is not used;
7. 1111 – w_1 and w_2 are used, FDL buffer is used and contains one burst, w_{ap} is used;
8. 1120 – w_1 and w_2 are used, FDL buffer is used and it is full (contains two bursts), w_{ap} is not used;
9. 1121 – w_1 and w_2 are used, FDL buffer is used and it is full (contains two bursts), w_{ap} is used;
10. 1001 – w_1 is used, w_2 and FDL are not used, w_{ap} is used;
11. 0101 – w_1 is not used, w_2 is used, FDL is not used, w_{ap} is used;
12. 0001 – w_1, w_2 and FDL are not used, w_{ap} is used.

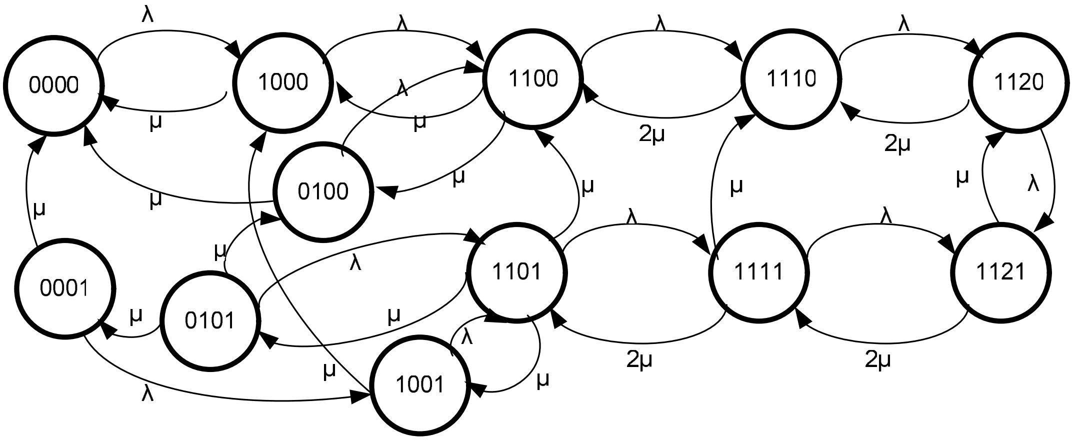

Fig. 3. State graph of the OBS core router.

$$\begin{cases} P_{0000}\cdot\lambda - P_{1000}\cdot\mu - P_{0100}\cdot\mu - P_{0001}\cdot\mu = 0, \\ P_{1000}\cdot(\lambda+\mu) - P_{0000}\cdot\lambda - P_{1100}\cdot\mu - P_{1001}\cdot\mu = 0, \\ P_{1100}\cdot(\lambda+2\mu) - P_{1000}\cdot\lambda - P_{1110}\cdot 2\mu - \\ -P_{0100}\cdot\lambda - P_{1101}\cdot\mu = 0, \\ P_{0100}\cdot(\lambda+\mu) - P_{1100}\cdot\mu - P_{0101}\cdot\mu = 0, \\ P_{1110}\cdot(\lambda+2\mu) - P_{1100}\cdot\lambda - P_{1120}\cdot 2\mu - P_{1111}\cdot\mu = 0, \\ P_{1101}\cdot(\lambda+3\mu) - P_{1111}\cdot 2\mu - P_{1001}\cdot\lambda - P_{0101}\lambda = 0, \\ P_{1120}\cdot(\lambda+2\mu) - P_{1110}\cdot\lambda - P_{1121}\cdot\mu = 0, \\ P_{1121}\cdot 3\mu - P_{1120}\cdot\lambda - P_{1111}\cdot\lambda = 0, \\ P_{1111}\cdot(\lambda+3\mu) - P_{1101}\cdot\lambda - P_{1121}\cdot 2\mu = 0, \\ P_{1001}\cdot(\lambda+2\mu) - P_{1101}\cdot\mu - P_{0001}\cdot\lambda = 0, \\ P_{0101}\cdot(\lambda+2\mu) - P_{1101}\cdot\mu = 0, \\ P_{0001}\cdot(\lambda+\mu) - P_{0101}\cdot\mu - P_{1001}\cdot\mu = 0, \\ P_{0000} + P_{1000} + P_{1100} + P_{0100} + P_{1110} + P_{1101} + \\ + P_{1120} + P_{1121} + P_{1111} + P_{1001} + P_{0101} + P_{0001} = 1. \end{cases} \quad (1)$$

The usage of the global balance concept for the Markov chains enables us to put down the (1) (for evaluation of the system state probabilities).

IV. PERFORMANCE EVALUATIONS

It is necessary to determine how packet loss depends on the contention resolution methods and OBS network characteristics (data transmission rate).

Data packets in the OBS networks are concatenated and transmitted in bursts. We assume that the maximum burst length is equal to TCP maximum window size (L = 64 kB).

Incoming data flows are concatenated, if they must be transmitted over the same wavelength. Concatenated flows are served as one burst flow of the intensity

$$\lambda = \sum_{i=1}^{n} \lambda_i \ [burst/s], \quad (2)$$

where n – number of burst flows, λ_i – intensity of the i-th burst flow.

The WDM systems are used in the OBS networks. Therefore we assume that the data will be transmitted in the WDM system's standard rates: R = 1, 2.5 and 10 G/s.

The intensity of the burst flow transmission over OBS network node

$$\mu = \frac{R}{L} \ [burst/s]. \quad (3)$$

The average number of the optical bursts in the FDL buffer equals

$$\overline{N_{FDL}} = 1\cdot(P_{1110} + P_{1111}) + 2\cdot(P_{1120} + P_{1121}), \quad (4)$$

where P_{1110} and P_{1111} – the probabilities of system states which have one burst in the FDL, P_{1120} and P_{1121} – the probabilities of system states which have one burst in the FDL.

The mean waiting time value (for the burst) in the FDL buffer is obtained in accordance with the Little's theorem, i.e.

$$\overline{W_{FDL}} = \frac{\overline{N_{FDL}}}{\lambda\left(1 - P_{1121}\right)}, \ [\mathrm{s}]. \quad (5)$$

The average time, spent by the burst in the FDL buffer, equals

$$\overline{T_{sys}} = \frac{1}{\mu} + \overline{W_{FDL}}, \ [\mathrm{s}]. \quad (6)$$

The probability of the deflection routing equals

$$P_{defl} = P_{1101} + P_{1121} + P_{1111} + P_{1001} + P_{0101} + P_{0001}. \quad (7)$$

The performance measures of the OBS network node, expressed in the form of a function of the queuing system parameters λ and μ, are shown in Fig. 4–Fig. 8.

The burst flow intensity (bursts/s) in our case is increased from 100 to 100000.

The formula (3) gives the intensities of burst flow transmission over OBS network node, which has data transmission rates R = 1, 2.5 and 10 Gb/s, equal to μ_1 = 1907.35 bursts/s, μ_2 = 4768.37 bursts/s and μ_3 = 19073.5 bursts/s.

The burst loss probability ($P_{loss} = P_{1121}$) as a function of burst flow intensity (λ) is presented in the Fig. 4. It increases when the burst flow intensity gets bigger. The dependency is not linear. Burst loss probability gets smaller for bigger burst flow transmission intensity (μ) values. In the given example, if λ = 40000 bursts/s and the data transmission rate is increased from 1 Gb/s to 10 Gb/s, then the burst loss probability decreases ~ 88 %.

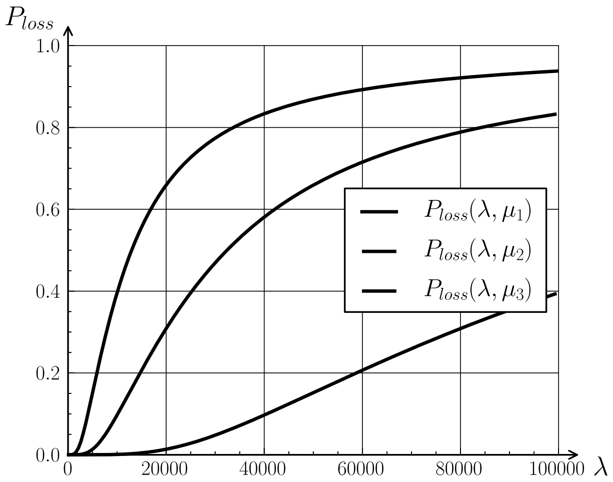

Fig. 4. The burst loss probability P_{loss} as a function of λ, given μ_1 = 1907.35 bursts/s, μ_2 = 4768.37 bursts/s, μ_3 = 19073.5 bursts/s, when FDL buffer can hold 2 bursts.

The similar model could be used to determine the optimal FDL capacity. The average number of bursts in the FDL as a function of burst flow intensity (λ) is presented in the Fig. 5.

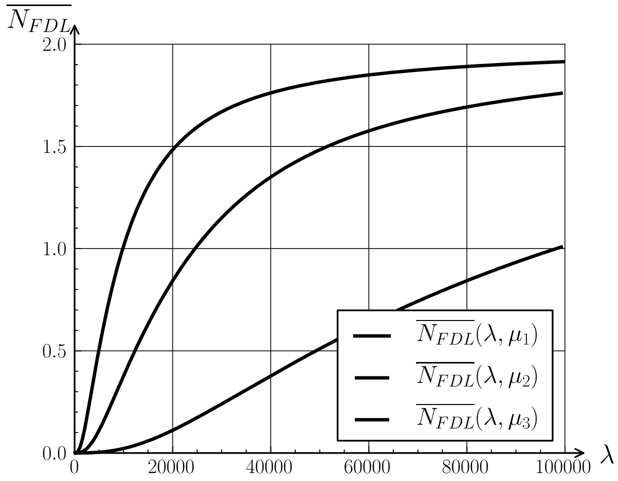

Fig. 5. The average number of bursts in the FDL as a function of λ, given μ_1 = 1907.35 bursts/s, μ_2 = 4768.37 bursts/s, μ_3 = 19073.5 bursts/s, when FDL buffer can hold 2 bursts.

The average number of bursts ($\overline{N_{FDL}}$) in the FDL can't be bigger than the FDL capacity. And the Fig. 5 shows that the $\overline{N_{FDL}}$ increases, if the burst flow intensity gets bigger, but it stays below the FDL capacity. In the given case, if λ reaches 40000 bursts/s and the data transmission rate increases from 1G b/s to 10 Gb/s, then the average number of bursts in the FDL decreases ~ 80 %. Therefore, the data transmission rate must be increased to decrease the burst loss when FDL capacity is small.

Although, the FDL decreases the loss of bursts, it increases the delay of burst transmission. The proposed model can evaluate the average waiting time in the FDL. The average waiting time in the FDL ($\overline{W_{FDL}}$) as a function of the burst flow intensity (λ) is presented in the Fig. 6.

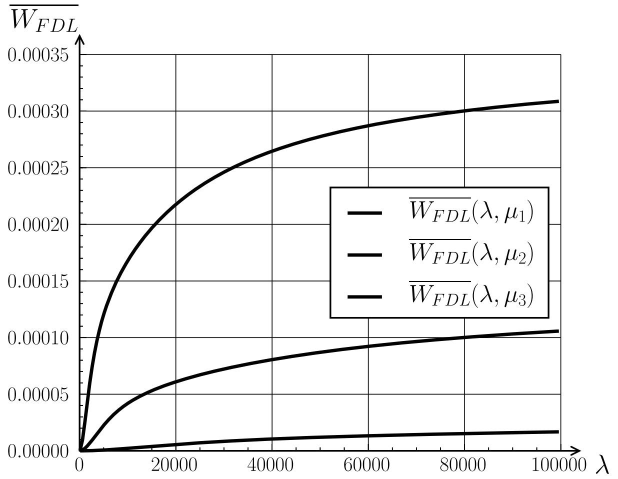

Fig. 6. The average waiting time in the FDL as a function of λ, given μ_1 = 1907.35 bursts/s, μ_2 = 4768.37 bursts/s, μ_3 = 19073.5 bursts/s, when FDL buffer can hold 2 bursts.

The average waiting time in the FDL increases when the burst flow intensity gets bigger. The $\overline{W_{FDL}}$ is getting smaller for bigger burst flow transmission intensity (μ) values. In the given example, if λ = 40000 bursts/s and the data transmission rate is increased from 1 Gb/s to 10 Gb/s, then the average waiting time in the FDL decreases ~ 96 %.

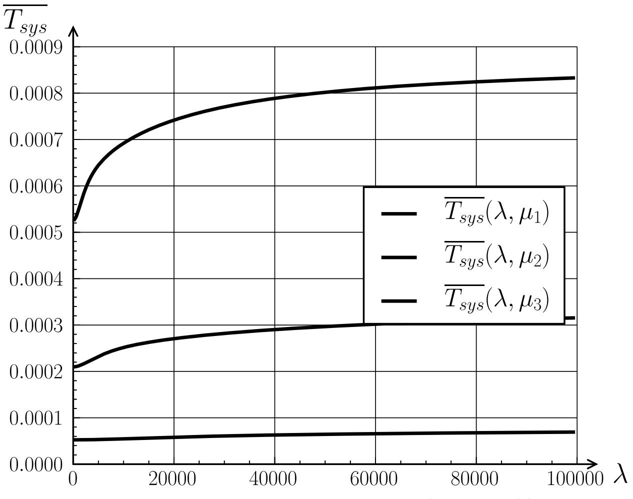

Fig. 7. The average time spent in the system as a function of λ, given μ_1 = 1907.35 bursts/s, μ_2 = 4768.37 bursts/s, μ_3 = 19073.5 bursts/s, when FDL buffer can hold 2 bursts.

The model also allows evaluating the average time spent in the system. It may be used to determine the quality of the real time services. The average waiting time spent in the system ($\overline{T_{sys}}$) as a function of burst flow intensity (λ) is presented in the Fig. 7.

The $\overline{T_{sys}}$ depends on $\overline{W_{FDL}}$ and burst flow transmission intensity (μ) according to the (6) formula. The average time spent in system in case of bigger burst flow intensity gets smaller for bigger burst flow transmission intensity (μ) values. In the given case, if λ = 40000 bursts/s and the data transmission rate is increased from 1 Gb/s to 10 Gb/s, then the average time spent in the system decreases ~ 93 %.

The proposed model also allows evaluating the impact of deflection routing mechanism. The probability of deflection routing (P_{defl}) as a function of burst flow intensity (λ) is presented in the Fig. 8.

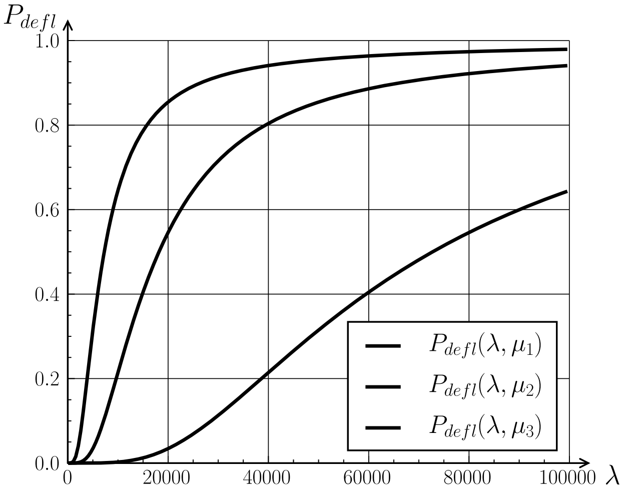

Fig. 8. The probability of deflection routing as a function of λ, given μ_1 = 1907.35 bursts/s, μ_2 = 4768.37 bursts/s, μ_3 = 19073.5 bursts/s, when FDL buffer can hold 2 bursts.

The probability of using of deflection routing (P_{defl}) increases when the burst flow intensity gets bigger. The P_{defl} gets smaller for bigger burst flow transmission intensity (μ) values. In the given example, if λ = 40000 bursts/s and the data transmission rate is increased from 1 Gb/s to 10 Gb/s, then the probability of deflection routing decreases ~ 77 %.

V. CONCLUSIONS

A solution has been proposed to reduce the burst losses in case of burst contention in highly loaded OBS network core nodes.

An analytical model has been created for the OBS core node to find out what impact has an application of various contention resolution strategies on the data transmission quality.

The amount of wavelength resources available at the node has the primary impact on the data transmission delay. It was revealed that FDL size affects burst loss in case of intensive burst flow only when the lack of wavelength resources in the core node occurs. Authors offer to apply burst segmentation only for the lower priority bursts. This solution would allow reducing lower priority data losses in the case of mixed priority burst incoming flow.

Every additional burst collision resolution strategy is applied in the core node, such as deflection routing or bursts segmentation, which allow reducing burst flow loss, but increase the time spent on the node at the same time, that is highly important for delay sensitive data transmission. Therefore future research is purposeful for determining an optimal amount of resources needed at the core node for the contention resolution. This task can be solved by means of simulation.

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