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Analysis of a Proposed Optical Burst Switching Core Node with Wavelength Converters and Deflection Routing

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ABSTRACT

The main commonly problem that arises in Optical Burst Switching (OBS) networks is a burst contention. Wavelength conversion and deflection routing are the most important switch fabric strategies to resolve this contention. In this paper, we study a mathematical model for a new proposal optical burst switching core node architecture. A performance measurement has been investigated by analytic the burst loss probability using steady-state occupancy probabilities and Poisson traffic model arrivals. Performance analysis results are presented at different values of the mean burst arrival rates with a core node design parameters such as wavelength conversion capability and deflection routing.

Keywords: Optical Burst Switching (OBS), wavelength conversion capability, burst loss probability, deflection routing

I. INTRODUCTION

Optical burst switching (OBS) networks are designed to achieve an intermediate solution between Optical Circuit Switching (OCS) and Optical Packet Switching (OPS) networks [1,2]. The OBS network transmits bursts between optical switching nodes that are interconnected via fiber links. Each fiber link supports multiple wavelength channels that assigned independently using Wavelength Division Multiplexing (WDM) [3,4]. Each burst has two parts: Control Burst (CB) and Data Burst (DB). The basic principle is to transmit the CB ahead of the DB by an offset time in order to configure the switches along the burst's route [5]. Optical switching nodes in an OBS network can either be edge nodes or core nodes [6]. The edge node may be ingress or egress node. The main ingress edge node task is to aggregate the data packets into bursts with an appropriate assembly algorithm [7]. The egress edge node is the destination network node that disassembled bursts into original data packets. While at the core node, the switch is configured to bypass the DB upon its arrival to the destined port processed using appropriate reservation protocol [8]. The core switches consist of an optical cross-connect (OXC) and a switch control unit (SCU) [9]. When the SCU receives a CB, it identifies the intended destination and refers the signaling processor to find the intended output port. If the output port is available, when the data burst arrives, the SCU configures the OXC to let the DB pass through. If the port is not available, contention occurs as more than one DB tries to reserve the same wavelength channel on an outgoing link. Then, the OXC is configured to solve that contention depending on the contention resolution policy implemented in the network.

When the contention occurs in the OBS network, one of contending DB is allowed to reserve the wavelength channel. For the other data bursts, one or a combination of contention resolution technique can be applied. The efficient contention resolution strategies are importance in the OBS networks [10], such as wavelength conversion [11], fiber delay lines [12], burst segmentation [13], and deflection routing [14]. The wavelength conversion and deflection routing techniques were shown to be the most effective contention resolution strategies for OBS networks [15-16]. Wavelength conversion is efficient and does not commence the delay in the data path, but it was expensive for deployment. In recent years wavelength conversion can be designed using Arrayed Waveguide Gratings (AWG) which are simple to fabricate, inexpensive and consume no power [17, 18]. Deflection Routing does not require any additional hardware so it can be easily implemented in existing network. Wavelength conversion is needed to switch the contended burst into other not occupied output wavelength channel at the same output fiber link. The contended burst redirected into another output link of the node using deflection routing. Otherwise, when the output port occupied with other bursts, and there is no any contention resolution mechanism available, then the burst will be blocked.

Various OBS core node architectures are investigated depending on the distribution of contention resolution mechanisms [19]. The aim of this paper is to numerical analyze a proposal OBS core node architecture with wavelength converters and deflection routing mechanism, presuming the mathematical model in M.H.Morsy *et al.* [20] to model the average burst loss probability and steady-state throughput performance. Unlike the mathematical model in the previous model where the OBS core node performance has been studied with wavelength conversion only using Dedicated Per-Input Line (DPIL) switch architecture. In our model architecture that supports Dedicated Per-Input/Output Lines wavelength converters and using deflected routing switching matrix, various architecture states are discussed in the optical burst switch.

The remainder of this paper is organized as follows. In section 2, we present a detailed description of our proposed model. Including the model architecture, the model assumptions, the state diagram, and the model equations. Section 3 is devoted to representing and discussing results of the derived performance measures for the proposed mathematical model. Finally, we conclude in section 4.

II. MODEL DESCRIPTION

A. The Model Architecture

A variety of an optical switch core node architecture is possible depending on the placement and availability of contention resolution mechanisms. For example, wavelength converters may be tunable wavelength converters (TWC) or fixed ones. It can be placed at the input and/or output ports of an optical burst switch. Moreover, each port of the switch may be equipped with its own dedicated converters, or the converters may be shared by all ports [21].

The proposed OBS intermediate node switch architecture is shown in Fig. 1. The node is equipped with an internally N input/output fiber (IF/OF) lines. For each incoming fiber link, there is an optical multiplexer which separates the incoming optical signal into w wavelength channels and then kept separated until they will be again multiplexed at the output fiber ports. It is assumed that there are a wavelength conversion and a deflection routing strategies for burst contention resolution. There are r dedicated Tunable Wavelength Converters (TWCs) implemented at each one of the input/output fiber lines, where only r wavelengths from a total w wavelength can be converted to any other free wavelength, $r \le w$, while the remaining w-r wavelengths are nonconvertible ones. The node is equipped internally with an optical space switching matrix with size $w\mathrm{N} \times w\mathrm{N}$.

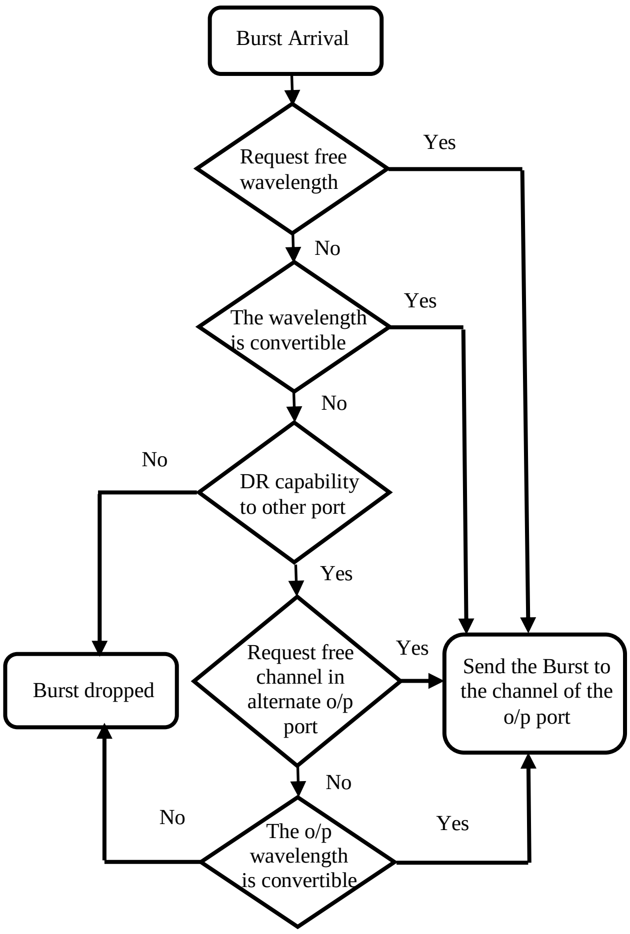

Figure 1: The OBS core node architecture

The core switch model flowchart is demonstrated at Fig. 2. In such architecture, the burst coming into the switch with a particular wavelength. It is assigned to a channel according to the CB information. If the needed wavelength is idle, then it will be reserved immediately for the data burst. Otherwise, if the incoming burst requests a busy wavelength, it can be converted into another wavelength using a set of an input dedicated converters' pool. If the contended burst has not opted for wavelength conversion capability, it can be deflected using deflection routing DR strategy, to some other port in the network. The deflected bursts at the output ports will be sent to other converters' pool or not depending on the need of wavelength conversion. The contending burst will be dropped if it cannot be contention resolved.

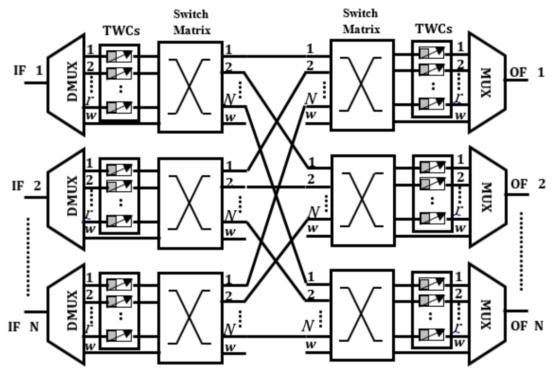

Figure 2: The OBS core node model flowchart

B. The Model Assumptions

Some assumptions are made for the traffic pattern in the switch:

- Such model is based on a Continuous-Time Markov Chain (CTMC) [22], assumes Poisson arrivals rate (α bursts/burst time) and exponential service times ($1/\mu$ time unit) which is equal to the average duration of the data burst, or the burst length, and it is constant in our analysis and equal to 50 per burst time.
- The output port for the incoming burst is uniformly distributed among all available output fiber ports. Thus, the behavior of a single output port is sufficient to model instead of considering all output ports of the node.
- M/M/w/w queue is modeled at the output port. For that queue, there are w servers in the system simulating the available w wavelengths in the node, also this queue is characterized by a maximum number of users in the system equal to w where there is no buffering capability in the node which is modeled by a queue length equal to zero.
- Our proposal model assumes the availability of 16 wavelengths/fiber link.
- The node conversion capability γ = 0, this means that the node has no wavelength conversion capability. Whereas if γ = 1, the node has full wavelength conversion capability and the w wavelengths are fully accessible.

- A deflection routing probability parameter $p = \frac{N-1}{w}$, is introduced in our analysis. The bursts which arrive at the node can be deflected to any of its output ports with the same probability (p). In other words, we consider the bursts which arrive at the node have the same deflection routing probability for all (N-1) output links.

C. State Diagram

Fig. 3 presents the general state diagram of the OBS network model. The state k where $k \in \{0, 1, 2, \ldots\ldots, w\}$ represents the node when it is currently serving k bursts.
This state diagram represents a birth-death process of the Markovian model of M/M/w/w queue with the adjusted birth rate.

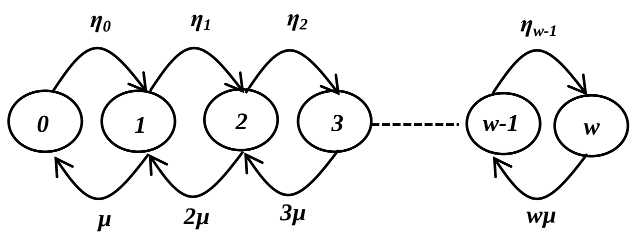

Figure 3: The state transition diagram of one-dimensional Markov process

At the first stage of the switch (the input wavelength converters and the deflection routing); the birth rate ηk_1 of this chain at state k_1 (the transition rate from state k_1 to k_1+1) is given by:

Birth Rate = arrival rate × [probability that an arrival requests a free wavelength + (probability that an arrival requests a busy wavelength × probability that the requested wavelength is convertible) + (probability that an arrival requests a busy wavelength × probability that the requested wavelength is not convertible × probability that an arrival deflected)], that is

$$\eta_{k1} = \alpha_1 \left(\left[\frac{w-k_1}{w} \right] + \left(k_1 . \frac{\gamma_1}{w} \right) + \left(k_1 . \frac{(1-\gamma_1)}{w} . p \right) \right) \quad (1)$$

For α_1 is the input mean arrival rate and γ_1 is the input wavelength conversion capability.
The death rate at state k_1 (transition rate from state k_1 to k_1-1) is set as $k_1.\mu$.
The deflected bursts from the first stage will be rerouted to the second stage (the output wavelength converters after deflection) with a mean rate α_2 given by:

$$\alpha_2 = \alpha_1 . (1-B_I) \quad (2)$$

where B_I is the average burst loss probability for the first stage. The birth rate ηk_2 for the second stage at the state k_2 will be:
Birth Rate = arrival rate × [probability that an arrival requests a free wavelength + (probability that an arrival requests a busy wavelength × probability that the requested wavelength is convertible)]

$$\eta_{k2} = \alpha_2 \left(\left[\frac{w-k_2}{w} \right] + \left(k_2 . \frac{\gamma_2}{w} \right) \right) \quad (3)$$

For γ_2 is the output wavelength conversion capability.

D. The Model Equations:

Now, a mathematical analysis is performed to evaluate the model performance; namely, the average burst loss probability P_B and the general steady-state throughput β_t. First, we could find the steady-state probabilities π_k (k = 0, 1, 2, … w) of the Markov chain explained in the previous part in Fig. 3, which actually is the steady-state probability that the Markov chain corresponding to Output Fiber (OF) in state k.
The cut equations from the state diagram in Fig. 3 are as follows:

$$\pi_1 = \frac{\eta_0}{\mu} \pi_0$$
$$\pi_2 = \frac{\eta_1}{2\mu} \pi_1 \quad \text{or} \quad \pi_2 = \frac{\eta_1}{2\mu} \frac{\eta_0}{\mu} \pi_0$$
$$\pi_3 = \frac{\eta_2}{3\mu} \pi_2 \quad \text{or} \quad \pi_3 = \frac{\eta_2}{3\mu} \frac{\eta_1}{2\mu} \frac{\eta_0}{\mu} \pi_0 \ldots\ldots \quad (4)$$

Repeating this until reaching an expression for the steady-state probability π_k in terms of π_0

$$\pi_k = \begin{cases} \frac{\eta_0}{\mu}.\pi_0 & ,k=1 \\ \frac{\prod_{i=0}^{k-1}\eta_i}{k!(\mu)^k}\pi_0 & ,k \geq 2 \end{cases} \quad (5)$$

but, $\sum_{k=0}^{w}\pi_k = 1$

then, $\pi_0 = \frac{1}{1+\frac{\eta_0}{\mu}+\sum_{j=2}^{w}\frac{1}{(\mu)^j.j!}.\prod_{i=1}^{j-1}\eta_i}$ (6)

substituting from (6) in (5), the general steady-state probability π_k can easily evaluate as next:

$$\pi_k = \begin{cases} \frac{\frac{\eta_0}{\mu}}{1+\frac{\eta_0}{\mu}+\sum_{j=2}^{w}\frac{1}{(\mu)^j.j!}.\prod_{i=1}^{j-1}\eta_i} & ,k=1 \\ \frac{\frac{\prod_{i=0}^{k-1}\eta_i}{k!(\mu)^k}}{1+\frac{\eta_0}{\mu}+\sum_{j=2}^{w}\frac{1}{(\mu)^j.j!}.\prod_{i=1}^{j-1}\eta_i} & ,k \geq 2 \end{cases} \quad (7)$$

which is π_{k1} for the first stage and π_{k2} at the second state. The average burst loss probability for the first stage B_I is the probability that a burst arrival is being blocked or dropped on the average, and can be calculated as follows:

$$B_I = (1\text{-p})[\pi_1.\frac{1}{w}.(1\text{-}\gamma_1)+\pi_2.\frac{2}{w}.(1\text{-}\gamma_1)+\ldots+\pi_{w\text{-}1}.\frac{w\text{-}1}{w}.(1\text{-}\gamma_1)+\pi_w]$$

$$B_I = (1-\text{p})[\pi_w + \sum_{i=1}^{w-1}\pi_i.\frac{i}{w}.(1-\gamma_1)] \quad (8)$$

Deflection routing is not applied (with a probability of 1-p), and the first term indicates the case when an arriving burst finds all w wavelengths channels occupied. On the other hand, the second term considers the case when there are idle channels on the output port but the burst requires conversion and it is dropped due to the lack of a suitable wavelength conversion 1 - γ_1.

The steady-state throughput for the first stage is β_1, that is the average number of successfully served burst arrivals by the node within a time interval equal to the burst duration;

$$\beta_1 = \sum_{k=0}^{w} k_1\pi_{k1} \quad (9)$$

The average burst loss probability for the second stage B_{II} will be:

$$B_{II} = \pi_w + \sum_{i=1}^{w-1}\pi_i.\frac{i}{w}.(1-\gamma_2)] \quad (10)$$

and the steady-state throughput for the second stage is β_2

$$\beta_2 = \sum_{k=0}^{w} k_2\pi_{k2} \quad (11)$$

Then, the total average burst loss probability P_B for both stages:

$$P_B = B_I + \pi_w.\text{p}.B_{II} \quad (12)$$

The total steady-state throughput will be

$$\beta_t = \beta_1 + \beta_2 \quad (13)$$

III. RESULTS AND DISCUSSION

In this section, we will illustrate the numerical results of the performance analysis that presents the dependency of the blocking probability and throughput of OBS core node on the average arrival rate α, the wavelength conversion capability γ, and the deflection routing capability p in different cases.

The decision for the wavelength conversion or deflection of the burst will be taken as in the four cases demonstrated in Table 1. Fig. 4 and 5 describes the variation of the overall burst blocking probability P_B and the total steady-state throughput β_t respectively, when increasing the average arrival rate corresponding to the wavelength conversion and the deflection routing capabilities.

TABLE I

THE DIFFERENT CORE SWITCH FOUR CASES

Case	Wavelength Conversion capability at	Deflection Routing p	Wavelength Conversion capability at

	I/P γ_1		O/P γ_2
Case_1	0	0	0
Case_2	1	0	0
Case_3	0	1	0
Case_4	0	1	1

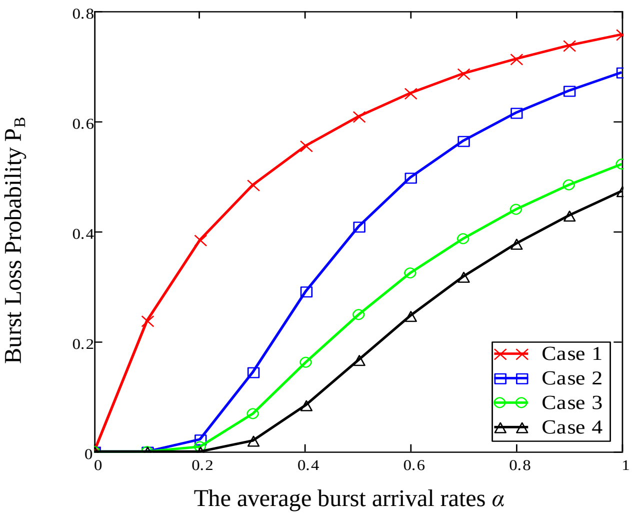

Figure 4: The overall Burst loss probability P_B vs. the average burst arrival rate α for the four cases.

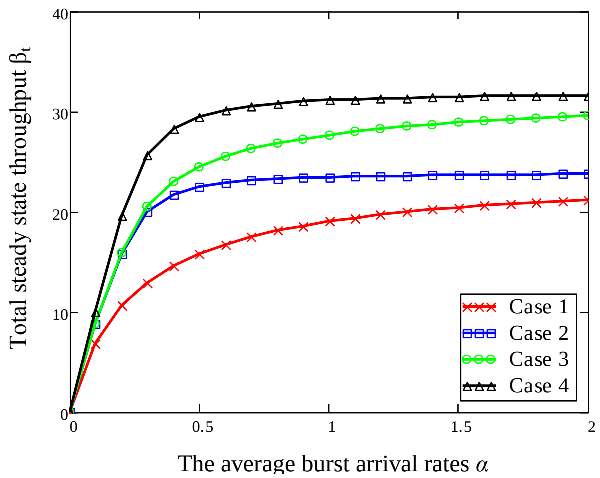

Figure 5: The total steady state throughput β_t vs. the average burst arrival rate α for the four cases.

Obviously the more traffic arrivals the more loss probability and the throughput increases. In the case of burst contention, some bursts will be either wavelength-converted at different wavelength channel or will be deflected to some other OF node link. The decision for the wavelength conversion of the burst or deflection of the burst will be taken as in the four cases demonstrated as follows:

Case_1, in this case, the arrival burst has no free wavelength and it has not any contention resolution capability (γ_1 = 0, p = 0) to avoiding the burst blocking. The blocking probability increases rapidly as increasing the number of burst arrivals.

In case_2, the arrival burst which has no free wavelength can be full wavelength convertible at the input port (γ_1 = 1). Without deflection routing (p = 0) the contended burst can go out with reasonable burst contention. The wavelength converters significantly reduce the mean burst blocking probability, particularly at low loads. The steady-state throughput will be increased rapidly at low traffic and then be fixed. That is due to that all wavelength channels become occupied. The burst loss probability and throughput results, in this case, reveals the consistency of our proposed model results with that of the previous model proposed by M.H.Morsy et al. [20], that involves the wavelength converters at the input ports.

In case_3, there are no wavelength converters at the input ports. On the other hand, it can be deflected to another link (γ_1 = 0, p = 1). The deflected burst not wavelength convertible at the output stage (γ_2 = 0) if there is no free wavelength in the alternate link. It is clear that the deflection routing marginally outperforms the wavelength conversion as a method to reduce the burst blocking probability compared to the previous case. The deflection routing enhances the switch performance with a significant value. With increasing in traffic arrivals, the throughput value increases and the steady state will take a while, than the previous case. That improving the performance is due to the burst have more wavelength channels chances to assign at different output ports.

Finally, in Case_4, there is no wavelength conversion at the input ports (γ_1 = 0). The contended burst can be deflected to another link with full deflection routing (p = 1). If the deflected burst has no free wavelength in the alternate output link, it will be full wavelength-convertible (γ_2 = 1). It is clear that a full wavelength conversion after the deflection routing gives greatest performance gain than other cases overall traffic loads. The burst has more available idle wavelength chances.

Therefore, a combination of both contention resolution methods with an appropriate architecture scheme reduces significantly the burst blocking probability and enhances the steady-state throughput values.

IV. CONCLUSION

Computing the blocking probability and the steady-state throughput of bursts for a proposed core node model architecture in an OBS network is illustrated. An analytical model has been created to evaluate the switch performance with wavelength conversion and deflection routing as contention resolution mechanisms. Numerical results are presented at different values of network average arrival rates at different cases corresponding to the existence of wavelength conversion and deflection routing capabilities. In the first case, the switch has not any contention resolution mechanism, in order to evaluate their individual influence on the switch performance. The result is a high burst loss. In other three cases, the contended bursts will be either wavelength-converted at the contending node or will be deflected to some other node in the network. From our results, it can be observed that using the deflection routing consistently reduces the blocking probability more than using the wavelength converters, especially at high burst arrivals. Furthermore, it is clear that using a full deflection routing followed by full wavelength converters at the output ports is the optimum case gives good performance values, particularly at low traffic. Consequently, an arrangement of both methods of contention resolution with a suitable architecture is required to achieve the greatest performance benefits overall burst rate arrivals.

These observations can be useful for the network designer to take a decision that which of the schemes should be employed to achieve optimized network performance.

Therefore future research is focused on determining an optimal amount of resources needed at the core node for the contention resolution. We can employ simulation means to resolve this task.

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