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Full Length Research Article

An Enhanced OBS Core Node Design Incorporating Wavelength Conversion and Deflection Routing Mechanisms

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Abstract— **The primary challenge in Optical Burst Switching (OBS) networks is the occurrence of burst contention. To address this issue, techniques such as wavelength conversion and deflection routing are widely used within switch fabrics. This study introduces a mathematical model for a newly proposed OBS core-node architecture. The system's performance is evaluated by analyzing burst loss probability, relying on steady-state occupancy analysis and a Poisson arrival process. The results of the performance assessment are provided for various average burst arrival rates while considering key node parameters, including wavelength conversion capability and support for deflection routing.**

Index Terms— Optical Burst Switching (OBS), wavelength conversion capability, burst loss probability, deflection routing

I. Introduction

Optical Burst Switching (OBS) represents a hybrid switching technique positioned between Optical Circuit Switching (OCS) and Optical Packet Switching (OPS) technologies. In this architecture, data bursts are transferred across optical nodes that are linked through fiber-optic connections. Each optical fiber accommodates several independent wavelength channels through Wavelength Division Multiplexing (WDM). A typical burst consists of two components: a Control Burst (CB) and a Data Burst (DB). The CB is transmitted earlier than the DB by a predefined offset interval, allowing sufficient time for configuring the switching path along the network.

OBS nodes are categorized into edge nodes and core nodes. Edge nodes serve as either ingress points, where incoming data packets are assembled into bursts according to selected aggregation algorithms, or as egress points responsible for disassembling bursts back into their original packets. Core nodes, on the other hand, are equipped to forward data bursts transparently once their switching configuration is set by the applied reservation protocol. Each core node incorporates an optical cross-connect (OXC) and a switch control unit (SCU). Upon receiving a CB, the SCU determines the desired output interface and allocates resources accordingly. If the required output wavelength is free, the SCU configures the OXC to forward the DB immediately upon arrival. However, when several bursts request the same wavelength on an outgoing link, contention occurs, and the OXC must handle it based on the implemented contention-handling policy.

During contention, only one burst can occupy the requested wavelength, while the others must be processed using one or more contention resolution approaches. Effective contention mitigation methods are essential in OBS networks and include wavelength conversion, fiber delay lines, burst segmentation, and deflection routing. Among these, wavelength conversion and deflection routing have been shown to deliver the highest performance benefits. Wavelength conversion allows a contending burst to be switched to a different free wavelength on the same output fiber, whereas deflection routing forwards the burst through an alternative output interface when its primary route is unavailable. If no resolution mechanism is possible and the output link remains occupied, the burst is ultimately dropped.

Various OBS core node architectures are investigated depending on the distribution of contention resolution mechanisms [18]. The aim of this paper is to numerical analyze a new proposal OBS core node architecture with wavelength converters and deflection routing mechanism, presuming the mathematical model in M.H.Morsy et al. [19] to measure the average burst loss probability 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 deflected routing switching matrix.

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 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 [20].

The OBS intermediate node switch architecture is shown in figure 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. There are r 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, $r \leq w$, while the remaining *w*-r wavelengths are nonconvertible ones. The node is equipped internally with a non-blocking switching matrix with size $wN \times wN$.

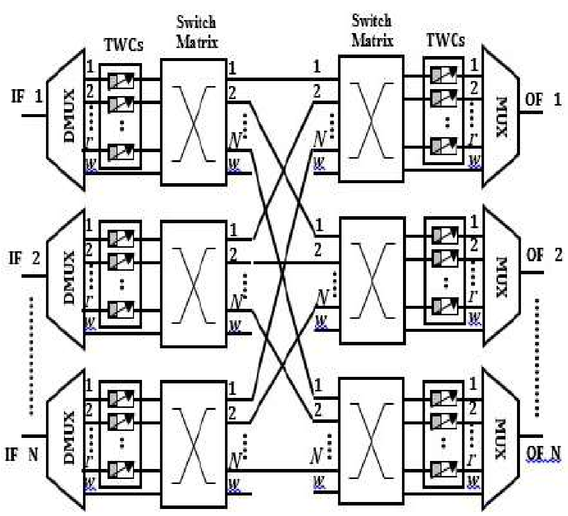

Fig. 1. The OBS core node architecture

In such architecture, there are two stages. In the first stage; after de-multiplexing phase, the burst might be sent to the converters' pool or not depending on the need of wavelength conversion. If the incoming burst requests a busy wavelength, the burst contends and then it will be converted if available. If the contended burst has not wavelength conversion capability, it will be deflected to some other port in the network. There are N-1 wavelengths in each fiber link are dedicated for deflection routing, were $N \leq w$. the switching matrix selects the right wavelength within the interface. In the second stage, the deflected bursts at the output ports will be sent to other converters' pool or not depending on the need of wavelength conversion.

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) [21], assumes Poisson arrivals (rate α bursts/burst time) and exponential service times (average service time 1/μ 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.
- An M/M/*w*/*w* queue with limited server accessibility is modeled at the output port. For that queue, there are *w* servers in the system simulating the available *w* wavelengths in the node.
- The M/M/*w*/*w* queue is also 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.
- The node conversion capability can be defined as $\gamma=\frac{r}{w}$. If γ=0, this means that the node has no wavelength conversion capability. If γ=1, the node has full wavelength conversion capability and the *w* wavelengths are fully accessible. Whereas if $0<\gamma<1$, the node has a partial wavelength conversion capability and the incoming burst will be blocked if the required wavelength is busy and nonconvertible.
- A deflection routing probability parameter $p=\frac{N-1}{w}$, $(0 \leq p \leq 1)$ is introduced in our analysis. The bursts which arrive at the node are deflected to all its output ports with the same probability (p_k). Therefore, we consider the deflection probability of one of N-1 remaining output ports, $p_2= \ldots\ldots = p_{N-1} = p_N$, and $\sum_{k=2}^{N}\{p_k | k \neq i\} = p$, where N is the number of output ports and p is the total of deflection routing probabilities.
- The model does not make any approximation for the distribution of the traffic arrivals.

C. State Diagram:

Figure 2 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.

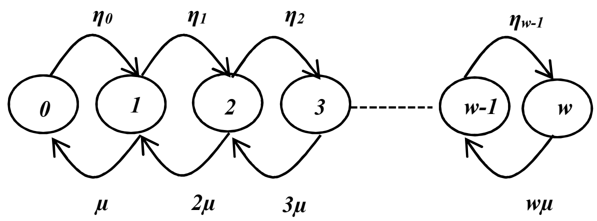

Fig. 2. The state transition diagram of one-dimensional Markov process

In the first stage; the birth rate η_{k1} 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 non-convertible × probability that an arrival deflected)], that is

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

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 with a mean rate α_2 given by:

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

where B_I is the average burst loss probability for the first stage. The birth rate η_{k2} for the second stage 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)]

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

D. The Model Equations:

Now, a mathematical analysis is performed to evaluate the model performance measurement; namely, the average burst loss probability P_b. 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 figure 2, 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.2 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

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

$$\text{but, } \sum_{k=0}^{w}\pi_k=1 \text{ then, } \pi_0=\frac{1}{1+\frac{\eta_0}{\mu}+\sum_{j=2}^{w}\frac{1}{(\mu)^j.j!}.\prod_{i=1}^{j-1}\eta_i} \quad (6)$$

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

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

The average burst loss probability P_b 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:

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

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

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

$$B_{II}=\pi_w+\sum_{i=1}^{w\text{-}1}\pi_i.\frac{i}{w}.(1\text{-}\gamma_2)] \quad (9)$$

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

$$P_b=B_I+\frac{\alpha_2\times B_{II}}{\alpha_1} \quad (10)$$

III. Results and Discussion

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

Figure 3 describes the variation of the overall blocking probability when increasing the average arrival rate corresponding to the wavelength capability in the two stages of the model and the deflection routing capability.

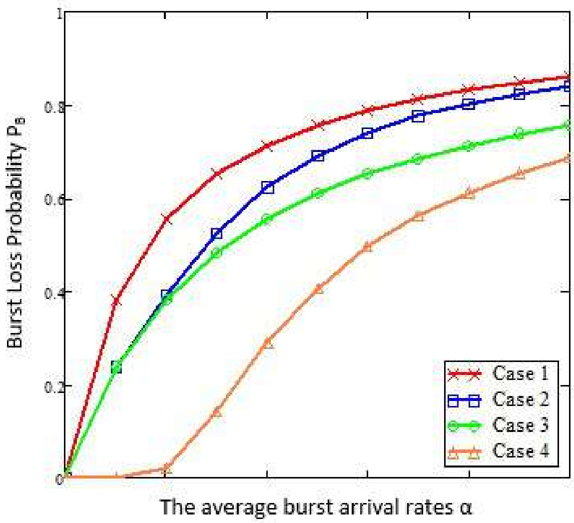

Fig. 3. The overall Burst loss probability P_B vs. the average burst arrival rate α for the four cases.

Obviously the more traffic arrivals the more loss probability. The blocking probability decreases significantly as we use contention resolution mechanisms. While burst traversing the network, in the case of contention of the bursts, some bursts will be either wavelength-converted at the contending node or will be deflected to some other node in the network. 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 first stage (γ_1=1). Without deflection routing (p=0) the contended burst can go out with reasonable burst contention probability. The wavelength converters significantly reduce the mean burst blocking probability, particularly at low loads. This case indicates a good consistency with a previous model proposed by Morsy *et. al.*

In *case 3*, the arrival burst is blocked and it cannot be convertible, then it is deflected to another link (γ_1=0, p=1). The deflected burst not wavelength convertible at the second stage (γ_2=0) if there is no free wavelength in the alternate link. Deflection routing marginally outperforms the wavelength conversion as a method to reduce the burst blocking probability compared to the previous case. The blocking probability as the same as the previous case at low loads. However, at high loads, the deflection routing is more effective than wavelength conversion to reduce the burst blocking probability.

Case 4, the arrival burst that is blocked with no wavelength conversion at the first stage (γ_1=0) is deflected to another link (p=1). If the deflected burst has no free wavelength in the alternate output link, it will be wavelength convertible (γ_2=1). It is clear that the wavelength conversion existence with the deflection routing gives greatest performance gain than other cases overall traffic loads. Therefore, a combination of both contention resolution methods reduces significantly the burst blocking probability especially at low burst arrivals with good results.

IV. Conclusion

The evaluation of burst blocking probability at an OBS core node is presented through an analytical framework developed for a newly proposed core-node architecture. The model assesses switching performance when wavelength conversion and deflection routing are employed as contention-handling techniques. The analysis includes different scenarios based on varying average burst arrival rates and the availability of each contention resolution feature.

In the baseline scenario, where no resolution mechanism is applied, the switch experiences a significantly high burst loss, allowing assessment of the isolated effect of each technique. In the other three scenarios, contending bursts are either shifted to an available wavelength or redirected through an alternate path within the network. The obtained results show that applying contention mitigation strategies greatly reduces burst loss, especially under light traffic conditions. Furthermore, the findings indicate that deflection routing consistently achieves lower blocking probabilities compared to wavelength conversion at higher load levels. Nevertheless, combining both approaches provides the most substantial improvement across all traffic intensities.

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