Estimation of Resources Availability in OBS Networks: A QoS-Based Approach

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Abstract
Optical burst switching (OBS) technology is one of the promising solutions for the next generation Internet backbones. One of the major issues in the design of optical burst-switched networks is the estimation of the availability of network resources needed for the transmission of an input traffic while ensuring the required quality of service (QoS). A few works have addressed the availability issue in the design of OBS networks. In this paper, we present a novel scheme to estimate resources availability in an OBS network based on node architecture suitable for contention resolution and QoS provisioning. We develop a mathematical model to estimate the probability that the network or a network device is unavailable at a given point of time or during a time slot. Also, we perform a simulation study to validate the proposed scheme and give an idea about the effects of some network and traffic parameters on the availability of network resources and the provided QoS.
Keywords: *OBS, QoS, Resources Availability*

1. Introduction

Among the promising solutions for next generation Internet backbones, one can consider the optical burst switching (OBS) technology [1, 2]. Unfortunately, the current state of this technology cannot support the management of a suitable QoS support, which may constitute a major challenge in service offerings over WDM. One of the major issues in the development of OBS services is the estimation of the network resources availability. The availability of network resources addresses two aspects: the availability of optical devices and the availability of services. While the former is addressed based on statistical behavior of the network devices, the latter should consider the stack of protocols involved in conducting the resource allocation and reservation in addition to the estimation techniques used to report on the system state to decide about the availability.

A few works have considered the estimation of resources availability in optical burst switched networks [3, 4, 5, 8]. Nevertheless, most of the developed studies focus on the analysis and the characterization of network components' physical failures. In this paper, we address the availability issue in the deployment of the OBS technology based on a QoS-oriented approach; concept which consists to estimate the availability of the needed resources to transmit a given input traffic while ensuring the required QoS in terms of delay, traffic loss, and delay variation (gigue). The presented study is mainly based on the development of an analytic model to estimate resources availability in an OBS network based on a novel OBS node architecture suitable for contention resolution and QoS provisioning [6]. Mainly, we present a mathematical tool to estimate the probability that the network or a network device is unavailable at a given point of time or during a time slot. Basically, we analyze the probability of unavailability of the transmission and buffering units which constitute the most important components of an OBS node. Also, we develop a simulation study to validate the proposed scheme and give some numerical results about the resources availability of the considered OBS network architecture.

The remainder of the paper is organized as follows. Section 2 discusses the main aspects of the considered OBS network architecture. Section 3 presents the analytic model developed to help an efficient mathematical analysis of OBS network resources availability. Section 4 focuses on the estimation, through simulation and mathematical analysis, of the availability of the main transmission resources in the considered OBS network architecture. Section 5 concludes the paper.

2. OBS Network Architecture

2.1 OBS Node Architecture

A complete description of the OBS network architecture considered in this paper can be found in [6]. As it is illustrated in figure 1, an OBS node architecture is composed of N input/ output ports. Each input/output port is assumed to handle multiple wavelengths using multiplexers and demultiplexers. An OBS node is mainly composed of: a switching unit (SU), a waiting unit (WU), a switching control unit (SCU), an input processing unit (IPU), and an output processing unit (OPU).

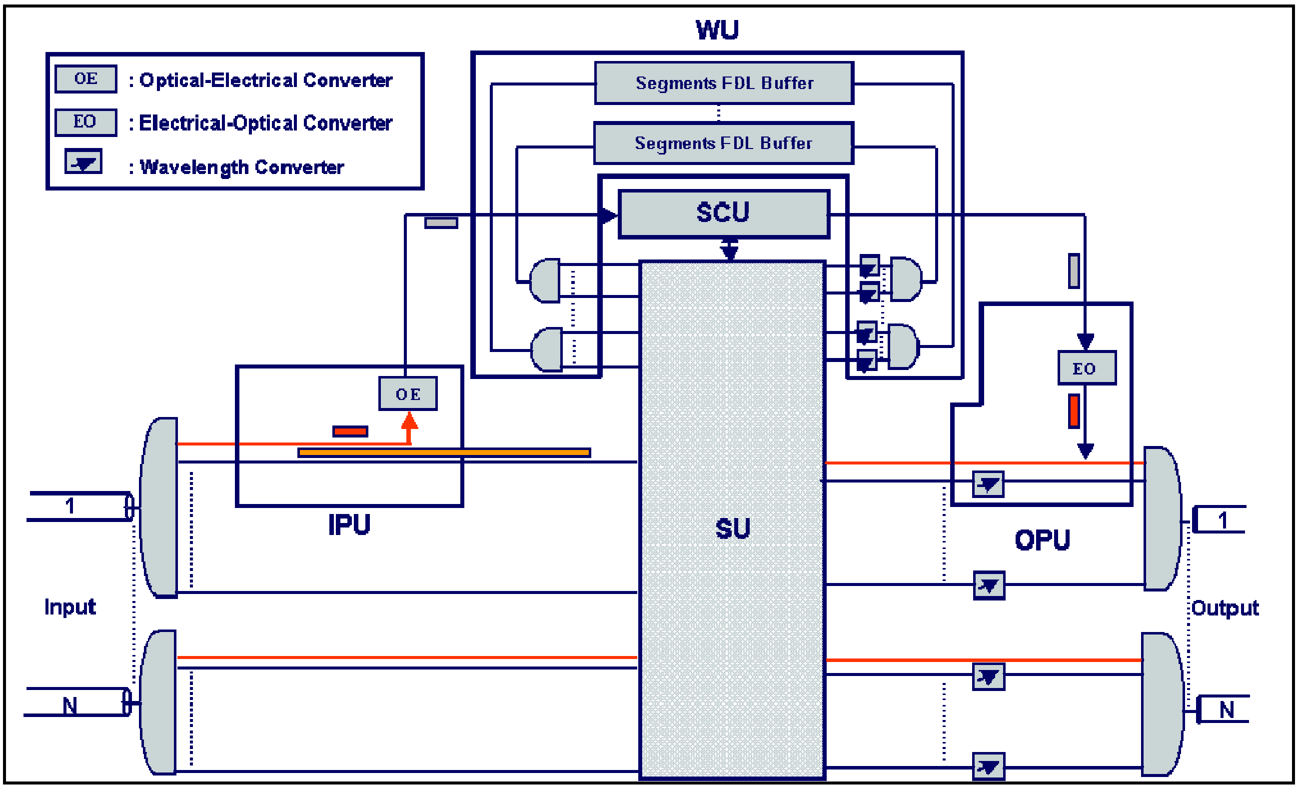

Figure 1: OBS node Architecture

Switching Unit: It allows the transfer of the input traffic units to the intended output channels, or to an appropriate fiber delay line (FDL) in the case of output port contention.

Waiting Unit: It is composed of a set of shared multi-wavelengths FDL buffers, used for output ports contention resolution. A Feed-backward FDL buffering mechanism is used to allow a delayed traffic unit emerging from an FDL buffer to be (re)buffered, in case of successive contentions. WU comprises also a set of full range wavelength converters used for FDL buffers conflicts resolution.

Switch Control Unit: It is responsible for the supervision of the SU activity as well as the reservation of the needed transmission resources (e.g., wavelengths, FDL buffers). Also, it manages signaling traffic, and it is responsible for contention resolution.

Input Processing Unit: An Input Processing Unit is associated with each input channel. Mainly, it is responsible for the reception and the OE (Optical/Electrical) conversion of burst header packets.

Output Processing Unit: An Output Processing Unit is associated with each output channel. It is mainly used for wavelength conversion in the case of contention. Also, it is used for conversion of the control packets to the optical domain once treated by the SCU.

2.2 Burst Assembly and Signaling Schemes

The JET-like signaling protocol and the burst assembly mechanism proposed in [7] are extended to the context of the considered OBS network architecture. We consider a timer-based composite burst assembly mechanism that assembles packets in segments and segments in bursts. A burst is a pure payload composed of a set of fixed-length segments. A segment is composed of a fixed number of packets of the same traffic type. A traffic type is defined a set of QoS attributes in terms of traffic loss and transfer delay. Once created, a data burst is preceded by a control packet, regrouping burst related control information, to configure the switches along the burst's path. The following control information are considered for a burst specification:

- **Offset time:** the period of time separating the control packet and the associated burst transmission start.
- **Burst-Length:** Number of segments in the burst.
- **Routing information:** Burst destination edge node.
- **Delay constraint:** Burst transfer delay threshold. This parameter is used to estimate a segment maximum blocking delay.

2.3 Contention Resolution Scheme

A detailed description of the contention resolution scheme implemented on the considered OBS network architecture can be found in [6]. Based on dynamic parameters of the observed traffic, the adopted contention resolution scheme works as follows: For every data segment Si, we mainly consider two parameters:

- **Si_MBD:** maximum network-wide buffering delay.
- **Si_BD:** measured online network-wide buffering delay.

In the case of an output channel contention between two segments Si, and Sj, the SCU compares the differences (Si_MBD - Si_BD), and (Sj_MBD - Sj_BD). The segment that has the lower difference is privileged. In case of equality, the segment of the least tolerant traffic type in terms of traffic loss is privileged. In case of contention, the privileged segment is switched to the appropriate output channel, while the other is routed to another available wavelength, if any. If no wavelength is available, a FDL buffer is used. If no FDL buffer is available, it is then dropped. Due to end-to-end transfer delay constraints, a data segment is dropped when the maximum authorized blocking delay is exceeded.

The deployment of such contention resolution scheme requires a real time update of segments network-wide incurred buffering delay (Si_BD). This is performed by the signaling scheme through the exchange of a control message each time a data segment is blocked or dropped.

3. OBS Network Modeling

In the following of this section, we present the analytic model developed for a mathematical analysis of resources availability in an optical burst switched network based on the above presented OBS node architecture. First, we consider the modeling of an OBS node. Then, we try to generalize the developed model at a network level.

3.1 OBS Node Modeling

Notations and Modeling Assumptions: We consider a network system with one traffic type. We suppose that time is slotted, and the duration of a time slot is equal to a segment transmission time (segtt). Let I_k: [k.segtt, (k+1).segtt], k≥0, denotes the k^{th} time slot. The arrival of data segments that are addressed to a specific output port of an OBS node, during a time slot I_k ,is assumed to be a Poisson process with rate λ^k (λ_0^k). Let m denotes a segment maximum WU-visits number. Let ST_j, $0 \le j \le m$, represents the traffic sub-type consisting of data segments that have been delayed j times. Let λ_j^k denotes the arrival rate of ST_j data segments during time slot I_k. Let w be the number of wavelengths available at each output port, and d the buffering capacity of the waiting unit. Let $PTUNA^k$ and $PWUNA^k$ denote respectively the probability of non availability of the transmission and the waiting units of the considered OBS node architecture during time slot I_k. Finally, we denote by γ_j^k the departure rate of ST_j data segments during time slot I_k. To estimate the resources availability for a given input traffic type, we consider here that all traffic sub-types generated based on the encurred blocking delay (ST_j, $0 \le j \le m$) are managed in an identical manner.

Analytic Model: Once the above assumptions are made, it becomes easy to model an output port of the considered OBS node architecture. The model, which is depicted by Figure 2, is an open queuing network system composed of two stations. Station 1, which represents the output port transmission unit is a M/D/w/w station with FIFO service type. Station 2, which represents the waiting unit is a M/D/d/d station with FIFO service discipline. The whole system is assumed to handle one customers' class, which correspond to the input traffic type.

Let us consider the path followed by a customer (segment) through the proposed queuing network model. Received at a time slot I_k, a data segment (i.,e. customer of sub-type ST_0) can be serviced immediately or be blocked. In the first case, the customer leaves the system after being serviced during a fixed duration *Segtt* (sgment transmission time). In the second case, the customer is sent to station 2, where it can be serviced immediately or be dropped. In the first case, a FDL buffer is allocated to this customer during a service time *Segtt*. Then, the customer moves to station 1 as a customer of sub-type ST_1. Each time the customer returns to station 1, it moves to the next sub-type (ST_2, ST_3,…, ST_m). A customer of sub-type ST_m, which cannot seize one transmission server at station 1 will be dropped.

3.2 Model Generalization: OBS Network Modeling

Based on the queuing network system developed for OBS node modeling, an analytic model can be easily developed to help an efficient mathematical analysis of an optical network based on the considered OBS node architecture. In fact, each network node can be modeled by a queuing network system as presented in figure 1. The arrival rate of a given traffic sub-type (ST_j, $0 \le j \le m$) at the input of a network node on a given path is equal to the departure rate of the same traffic sub-type at the upstream node on the considered path. The departure rate of ST_j data segments at the ingress node of a given path can be estimated based on the analysis of the queuing network system proposed for an OBS node modeling as will be presented in the following subsection. Given the arrival rate of ST_j data segments on the different paths at the input of a given network node n, we can estimate the total arrival rate of STj data segments at the input of node n which is equal to the sum of the arrival rates on the different path. Therefore, we can estimate the total arrival rate of each traffic subtype at the

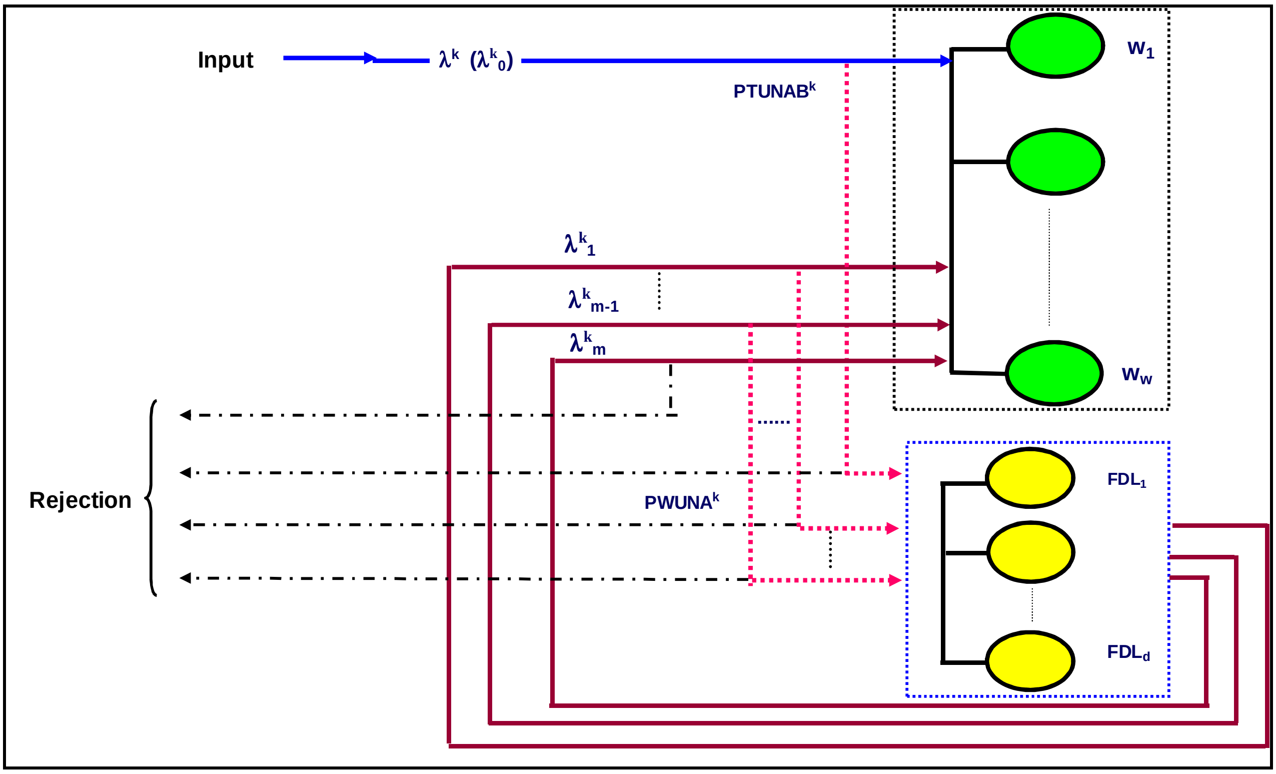

Figure 2: OBS Node Modeling

input each network node at a given time slot. This may help the estimation of the availability of each network node, and so the analysis of network resources and services availability.

3.3 Model Analysis

In this section, we address the analysis of an optical network based on the above presented OBS node architecture. We mainly consider the analysis of the traffic load and the traffic intensity at the input of the transmission and buffering units of a given network node n. These parameters are needed for the estimation of the availability of the transmission and buffering units at a given network node, and thus the estimation of network availability.

Let consider the following parameters:

- $\lambda_j^{n,k}$, $0 \le j \le m$, $k \ge 0$: the total arrival rate of ST_j data segments at the input of the transmission unit of network node n during time slot I_k.
- $\lambda^{n,k}$, $k \ge 0$: the total segments arrival rate at the input of the transmission unit of node n during time slot I_k.
- $\rho^{n,k}$, $1 \le n \le L$, $k \ge 0$: the total traffic intensity estimated for the transmission unit queuing station of node n during time slot I_k.
- $\chi_j^{n,k}$, $0 \le j \le m$, $k \ge 0$: ST_j the total arrival rate of ST_j data segments at the input of the buffering unit of network node n during time slot I_k.
- $\chi^{n,k}$, $k \ge 0$: the total segments arrival rate at the input of the waiting unit of node n during time slot I_k.
- $\varphi^{n,k}$, $k \ge 0$: the total traffic intensity estimated for the buffering unit queuing station at node n during time slot I_k.

Based on the queuing network system developed for a mathematical analysis of an OBS network node, the following expressions hold between the considered parameters:

$$\rho^{n,k} = Segtt \cdot \lambda^{n,k} \quad (1)$$

$$\lambda^{n,k} = \sum_{j=0}^{m} \lambda_j^{n,k} \quad (2)$$

As it is shown in expression (2), the analysis of the total segments arrival rate at the input of a network node n requires the analysis of the total arrival rate of the different traffic subtypes STj, $0 \le j \le m$. This requires the analysis of the departure rate of ST_j data segments during time slot I_k at the upstream node (n-1) on each path p crossing node n, $\gamma_j^{(n-1),p,k}$, $k \ge 0$, $n > 1$.

Let $\lambda_j^{n,p,k}$ and $\gamma_j^{n,p,k}$ denote respectively the arrival and the departure rate of ST_j data segments at node n through path p during time slot I_k, ($n \ge 1$, $k \ge 0$). Based on the queuing network system developed for OBS node modeling, we could establish the following expressions for the analysis of $\lambda_j^{n,p,k}$, $1 \leq n$, $0 \leq j \leq m$, $k \geq 0$:

$\lambda_0^{1,p,k}$, $k \geq 0$: given as a characteristic of the received traffic at the input of network path p (node 1) during time slot I_k.

For $1 \leq j \leq m$, we have:

$$\lambda_j^{1,p,k} = \lambda_0^{1,p,(k-j)} . \prod_{l=0}^{(j-1)} PTUNA^{1,(k-j)+l} . (1\text{-}PWUNA^{1,(k-j)+l}) \quad (3)$$

where $PTUNA^{n,k}$ and $PWUNA^{n,k}$ denote respectively the probability of non availability of the transmission and the waiting units of network node n during time slot I_k.

For a network node n on a given network path p, we have:

$$\lambda_j^{n,p,k} = (1\text{-}PTUNA^{n-1,k}).\left[\lambda_j^{n-1,p,k} + \left(\sum_{l=0}^{j-1} \lambda_l^{(n-1),p,(k-j)+l} . \prod_{t=l}^{j-1} PTUNA^{n,(k-j)+t}.(1\text{-}PWUNA^{n,(k-j)+t})\right)\right] \quad (4)$$

Once the arrival rates are analyzed, we could estimate the departure rate of each traffic subtype at an OBS node n through a network path p during time slot I_k, $\gamma_j^{n,p,k}$. $\gamma_j^{n,p,k}$ is given by the following expression:

$$\gamma_j^{n,p,k} = \lambda_j^{n,p,k} . (1 - PTUNA^{n,k}) \quad (5)$$

Moreover, we have established the following expressions for the analysis of the input traffic rate and the traffic intensity relative to the waiting unit queuing station:

$$\varphi^{n,k} = Segtt . \chi^{n,k} \quad (6)$$

$$\chi^{n,k} = \sum_{j=0}^{m} \chi_j^{n,k} \quad (7)$$

As it is shown in expression (2), the analysis of $\chi^{n,k}$ requires the analysis of $\chi_j^{n,k}$, $0 \leq j \leq m$, $k \geq 0$. Based on the above presented analytic model, we could establish the following expression:

$$\chi_j^{n,k} = \lambda_j^{n,k} . PTUNA^{n,k} \quad (8)$$

4. OBS Network Resources Availability

In this section we focus on the estimation of the availability of the needed network resources to transmit an input traffic while ensuring the required quality of service (QoS). Mainly, we address the estimation of the availability of the transmission and the buffering units which constitute the most important components of a network node in the considered OBS network architecture. The estimation of resources availability is carried out through simulation and mathematical analysis based on the above presented analytic model.

4.1 Mathematical Analysis

Let recall that $PTUNA^{n,k}$ denotes the probability of non availability of the transmission unit at a network node n during time slot I_k. The transmission unit may be unavailable due to two main raisons: a physical failure and the lack of wavelengths (i.e., all wavelengths are busy). Let $PTUPF^{n,k}$ and $PTUPF^{n,k}$ denote respectively the probability of unavailability of the transmission unit due to a physical failure and the lacks of resources. Thus, we have:

$$PTUNA^{n,k} = PTUPF^{n,k} + PTUFU^{n,k} \quad (9)$$

$PTUPF^{n,k}$ can be estimated based the on the analysis of the mean time between failures (MTBF) parameter for the transmission unit at node n [8]. Using the well known Erlang-B formula, we could established the following expression for the analysis of $PTUPF^{n,k}$:

$$PTUFU^{n,k} = \frac{(\rho^{n,k})^w / w!}{\sum_{i=0}^{i=w} (\rho^{n,k})^i / i!} \quad (10)$$

Substituting $PTUPF^{n,k}$ by its expression in (10), we can obtain the following expression for the analysis of the probability of non availability of the transmission unit at a network node during a given time slot I_k:

$$PTUNA^{n,k} = PTUPF^{n,k} + \frac{(\rho^{n,k})^w / w!}{\sum_{i=0}^{i=w} (\rho^{n,k})^i / i!} \quad (11)$$

Like the transmission unit the waiting unit, which constitutes a critical component in the design of the considered OBS node architecture, may be unavailable due to a physical failure and the lack of FDL buffers. Let recall that $PWUNA^{n,k}$ denotes the probability of non availability of the waiting unit at network node n during time slot I_k. Let $PWUPF^{n,k}$ and $PWUPF^{n,k}$ denote respectively the probability of unavailability of the waiting unit due to a physical failure and the lacks of resources. Therefore, we can establish the following expression:

$$PWUNA^{n,k} = PWUPF^{n,k} + PWUFU^{n,k} \quad (12)$$

$PWUPF^{n,k}$ can be estimated based on statistical behavior of the waiting unit at node n. Based on the above presented analytic

IJCSI International Journal of Computer Science Issues, Vol. 10, Issue 6, No 2, November 2013
ISSN (Print): 1694-0814 | ISSN (Online): 1694-0784
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model, the following expression could be established for the analysis of $PWUPF^{n,k}$:

$$PWUFU^{n,k} = \frac{(\varphi^{n,k})^{d} / d!}{\sum_{i=0}^{i=d} (\varphi^{n,k})^{i} / i!} \qquad (13)$$

Based on (12) and (13), we obtain the following expression for the analysis of the probability of non availability of the waiting unit:

$$PWUNA^{n,k} = PWUPF^{n,k} + \frac{(\varphi^{n,k})^{d} / d!}{\sum_{i=0}^{i=d} (\varphi^{n,k})^{i} / i!} \qquad (14)$$

Based on the estimation of the probabilities of non availability of the transmission and the waiting units, we can estimate the probability of unavailability of a network service. Let $PNSNA^{n,k}$ denotes the probability of non availability of network service at network node n during time slot I_k. $PNSNA^{n,k}$ is given by the following expression:

$$PNSNA^{n,k} = PTUNA^{n,k} + PWUNA^{n,k} \qquad (15)$$

Substituting $PTUNA^{n,k}$ and $PWUNA^{n,k}$ by their expressions in (11) and (14), we obtain the following expression for the estimation of the network service non availability:

$$PNSNA^{n,k} = PTUPF^{n,k} + PWUPF^{n,k} + \frac{(\rho^{n,k})^{w} / w!}{\sum_{i=0}^{i=w} (\rho^{n,k})^{i} / i!} + \frac{(\varphi^{n,k})^{d} / d!}{\sum_{i=0}^{i=d} (\varphi^{n,k})^{i} / i!} \qquad (16)$$

4.2 Numerical Results

This subsection, presents the simulation study performed to validate the introduced scheme and present some numerical. Mainly, we consider the evaluation of mean values for the probabilities of unavailability of the transmission and the buffering units which constitute the most important components of a network node in the considered OBS network architecture. In the sequel, we will first present the simulated configuration and then some of the most of the obtain simulation results.

a) Simulation model

Simulation Configuration: Figure 3 shows the topology of the OBS network on which simulation is conducted. The network is composed of N core nodes (C_1, ..., C_N) and a set of

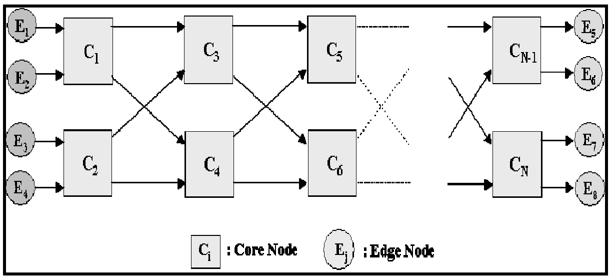

Figure 3: Simulated OBS network configuration

edge nodes (E_1, ..., E_8). Each core node is composed of two input/output ports. Each port is assumed to handle k wavelengths. A core node is also equipped of a WU with a buffering capacity limited to d segments. Also, we suppose that OBS node devices are characterized by constant physical failure probabilities deduced based on statistical behaviors. Simulation experiments consider that, an input traffic is generated at each input port of core nodes C_1 and C_2. The traffic received at an input port of a network node is supposed to be uniformly distributed between its two output ports.

Performance Metrics: Two performance metrics have been considered to evaluate the resources availability in the considered OBS network architecture: the probability of unavailability of the transmission unit and the probability of non availability of the waiting unit. The following input parameters have been considered for the performance evaluation: the mean time separating two successive bursts (iam), a burst length (burstl), wavelengths number (w), the buffering capacity (d), the maximum authorized WU-visits number (m), and the physical failure probability (pfp). For all simulation experiments, we have considered a null value for the php parameter, given that a very small value (ex. 10^{-6}) will have an insignificant impact on simulation results.

Simulation model accuracy: we have found it of great interest to present a clear indication about the accuracy of the developed simulation model before presenting simulation results. The validity of the developed simulation model is ensured by the use of random generators based on the well known pseudo-random numbers generator RAND. RAND belongs to a class of multiplicative linear congruential pseudo-random numbers generators (LC-PRNGs), which are well proved [9]. In addition to the use of suitable random generators, simulations experiments are conducted using appropriate sample-sizes; thus improving the credibility of the developed simulation model.

b) Numerical Results

In the following, we present a part of the obtained numerical to give an idea about the resources availability in the considered architecture.

Figure 4 plots the probability of the transmission unit unavailability versus the mean time separating two successive burst when, *k = 4 wavelengths*, *d = 5 segments*, *m = 3*, *pfp = 0.0*, and *burst length = 10 segments*. The figure shows that the probability of the transmission unit non availability decreases with the increase of the inter-arrival mean time *(iam)*. This can be explained as follow. The increase of bursts inter-arrival mean time decreases the input traffic load. This will increase the network resources availability and so the decrease of the probability of the transmission unit unavailability.

Figure 5 shows the impact of burst length *(burstl)* variation on the probability of the transmission unit non availability when, *k = 4 wavelengths*, *d = 5 segments*, *m = 3*, *pfp = 0.0*, and *iam = 100 µs*. We observe that the probability of the transmission unit unavailability increases with the increase of burst length. This is because, the increase *burstl* increases the network resources occupancy and so increases the probability of the transmission unit non availability.

Figure 6 plots the probability of the buffering unit unavailability versus the mean time separating two successive burst when, *k = 4 wavelengths*, *d = 5 segments*, *m = 3*, *pfp = 0.0*, and *burst length = 10 segments*. We observe that the probability of the buffering unit unavailability decreases with the increase of the inter-arrival mean time. This is because the increase of bursts inter-arrival mean time decreases the input traffic load, which decreases the network resources availability and so decreases the probability of the buffering unit unavailability.

Figure 7 presents the impact of burst length *(burstl)* variation on the probability of the buffering unit non availability when, *k = 4 wavelengths*, *d = 5 segments*, *m = 3*, *pfp = 0.0*, and *iam = 100 µs.* the figure shows that the probability of the buffering unit unavailability increases with the increase of burst length. This is because, the increase *burstl* increases the network resources occupancy and so increases the probability of network resources unavailability.

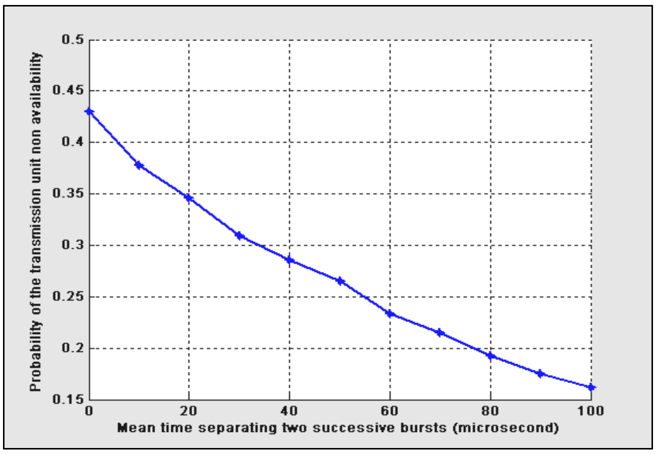

Figure 4: Transmission unit non availability vs. Inter-arrival mean time

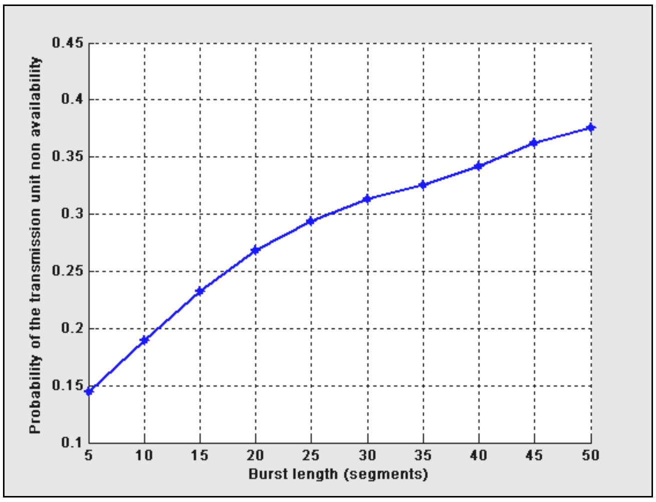

Figure 5: Transmission unit non availability vs. Burst length

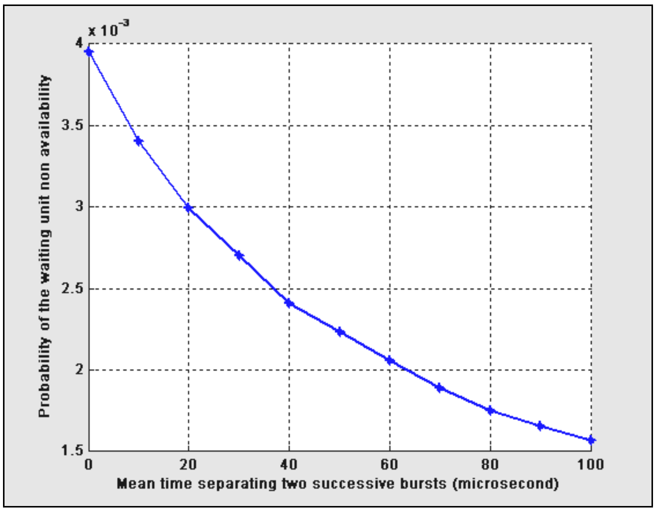

Figure 6: Buffering unit non availability vs. Inter-arrival mean time

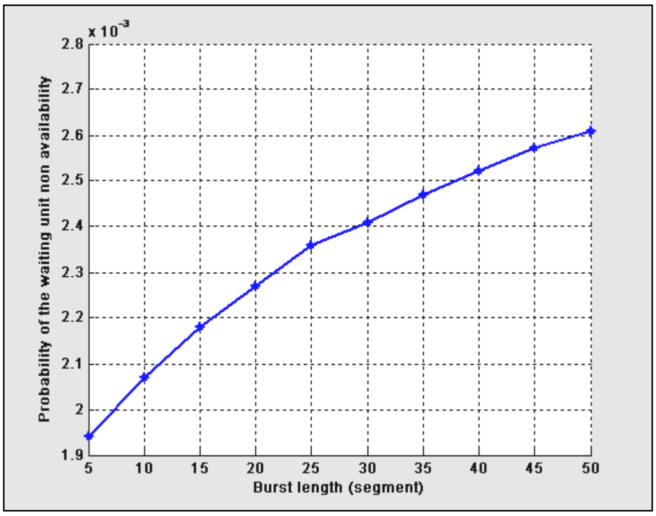

Figure 7: Buffering unit non availability vs. Burst length

5. Conclusion

In this paper, we have presented a QoS-oriented approach for the estimation of the availability of an OBS network based on a node architecture suitable for contention resolution and QoS provisioning. An analytic model has been developed to help an efficient mathematical analysis of resources availability in an OBS network. Simulations experiments have been also performed to validate the proposed approach and give an idea about the effects of some network and traffic parameters on the availability of network resources and the provided QoS.

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