

TELE-TRAFFIC ANALYSIS OF ALL-OPTICAL PACKET/ BURST SWITCHED NODES

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ABSTRACT

The blocking behavior of an asynchronous all-optical OBS/OPS node with shared wavelength converters has been successfully analyzed using classical Tele-traffic models. It has been proved that the Engset traffic model with modification in off time of an on-off traffic source is more realistic for analysis of such a system. It has been shown that the degree of conversion affects the blocking behavior of an optical packet/burst switched node which is not ignorable especially when the switching node under consideration is of medium or small port count. To be exact, continuous time Markov chains have been used. The important quantitative measures which are the time, call and traffic blocking have been evaluated and compared. Additionally, we have compared two approaches: 1) using pure Engset traffic source which assumes a lost packet/burst to be immediately removed from the system, 2) using modified Engset traffic source where the more realistic behavior is assumed that the lost packet/burst is to be dumped at the node which takes finite time and during this time source cannot generate more packets/bursts. The work done here will contribute to the Tele-traffic analysis of all-optical burst/package switched nodes.

Keywords: *Tunable wavelength converters, Loss call cleared model, Loss call delay dropped model, optical burst/package switching*

1) INTRODUCTION

Fiber links with the dense wavelength division multiplexing (DWDM) have promised to cater the future needs of transport networks. In these networks, optical circuit switching in the form of wavelength routed networks is already in place but not scalable as required by highly dynamic demands. Optical packet switching has been investigated from

early nineties and later a viable solution in the form of optical burst switching has been proposed (Qiao 99).

Optical packet/burst switching architecture defines a kind of out of band data switching. Switching nodes are configured with the help of control packets (CPs) which travel ahead of data traffic which is in the form of bursts/packets. The control packets are processed at each node after opto-electronic conversion, while on the availability of output wavelength channels, packets/bursts cut through the switching core all-optically. In the absence of first-in first-out (FIFO) buffers like in electronic domain the collision is indispensable in core nodes and entire research on OBS core nodes is to avoid and minimize the burst contentions.

For contention resolution many different approaches have been suggested both at node level and network level. Among popular approaches is deflection routing, wavelength conversion and burst segmentation. In deflection routing, burst contended are deflected to available alternative links for possible delivery to destination using alternative routes. Whereas, wavelength conversion is the most famous node based approach where, a contending bursts incoming wavelength is changed using wavelength changers at input or output links. Burst segmentation resolves contention partly by dropping only the colliding part of the burst. All these approaches might be combined; however, if contention cannot be resolved inevitably one of the contending bursts is to be dropped.

Among these approaches, wavelength conversion is considered to be a promising solution as wavelength conversion also increases fiber utilization. Wavelength conversion is performed using tunable wavelength converters (TWCs). In a node these converters may be available to each wavelength channel or may be shared as a pool of converters among channels of a single link or among all output links of a node, according to the node architecture. Due to the cost of wavelength converters, sharing is commonly preferred. Different architectures have been proposed to place the pool of shared converters. Among them are shared per node, shared per link and shared per wavelength.

2) BACKGROUND KNOWLEDGE

In the present study, shared per link architecture where a pool of wavelength converters is shared among all output links is discussed. Such architecture is not only preferred due to simple control, but it is very easy to perform stochastic analysis of the performance. To model such a node with shared converters at each output link, it is supposed that each link comprises of n_w wavelengths and in total n_f fibers are there as input/output links. Then the total number of competing sources for one output link is $n_s = n_f \times n_w$ (Overby 2009, Overby 2005, Zukerman 2004, Wong 2009). If the number of sources is very large in number, an output link can be easily modelled as Erlang loss system with wavelength channels taken as servers with exponential service. However, if this is not the case Engset traffic is more suitable for small to medium contending customers for resources (Overby 2009, Overby 2005, Zukerman 2004, and Wong 2009). Additionally, the authors in (Overby 2005, Overby 2007, and Zalesky 2009) have shown that pure Engset traffic model if applied directly will even over estimate the blocking probability and the reason is clear. In case of Engset, when a customer cannot find server, it is supposed to be vanished immediately and source can generate a new customer. However, in case of packet/burst switched node this is not the case, and in case of lost packet or burst, input wavelength channel is busy in dumping the lost packet/burst and during this time no more packets can be generated by the source. This situation is clearer when a large burst data is being dumped at the input link on the unavailability of output wavelength channel. The authors have suggested modifying the load by lengthening the off time of an on-off Engset source. The reason is that during clearing of lost packet source is not informed and it has to wait until packet/burst is vanished. The on-off Engset source is represented by a two state Markov chain and idle and busy times both are exponentially distributed with rates $1/\lambda$ and $1/\mu$ respectively. To cater the analysis, authors in (Zukerman 2004) used a two dimensional continuous-time Markov chain (CTMC), where there are two types of servers handling the incoming service requests. One carrying successfully switched packets and other are virtual servers handling service of packets/burst being cleared from the input channels due to the unavailability of output channels. The arrival rate in a state (i, j) is taken as $(n_s - i - j)\lambda$, where $(i, j) | 0 \geq i \leq n_w, 0 \geq j \leq n_s - n_w$. In case of pure Engset traffic model this rate

would be $(n_s - i)\lambda$ which shows Engset formula given below will actually over estimate the blocking probability.

$$E_T(A, n_W) = \frac{\binom{n_s - 1}{n_W} \alpha^{n_W}}{\sum_{r=0}^{n_W} \binom{n_s - 1}{n_W} \alpha^{n_W}} \quad (1)$$

For large sized switches, CTMC is not a computational feasible method and authors have suggested using numerical solutions with fixed point approximations (Akar 2007, Zukerman 2005). They have suggested lengthening the off-time of an on-off Engset source to compensate the time when source cannot generate due to lost packet/burst being dumped at the input wavelength channels.

The above mentioned technique is approximate in nature. As we are really interested in the behaviour of a switch with shared per link wavelength converter pool which is not a full access loss system, therefore, it is preferred to use CTMC for accurate analysis which is required. In the present study, both of the two models 1) simple Engset and 2) modified Engset are analyzed and compared. In simple one, a dropped packet/burst immediately vanish from the system called lost call cleared (LCC) and in modified Engset, a dropped packet/burst is supposed to make the input channel busy until completely dumped called lost call dropped (LCD) model. The blocking measures we have used are given in (Iversen2005) which are call blocking, time blocking and traffic blocking. It is also shown that traffic blocking is the most accurate measure in this case (Overby 2005). Enough results have been shown to prove that arrival model actually affect the performance analysis of switching node under consideration. The work here is being extended in results and material from the work already presented in (Hayat 2011). The rest of the paper is organized as follows.

Section 3 is dedicated for describing the node architecture in brief along with explanation of models considered and also the definitions of performance measures being used in this paper. Section 4 then presents the analytical analysis for both of the arrival models. The results are presented in the next section. Section 6 concludes the paper.

3) NODE ARCHITECTURE

The switching core of the node under consideration is supposed to be strictly non-blocking. The arrival of requests for output channels is supposed to be asynchronous. If total number of input/output fibers is n_f where each is equipped with DWDM equipment with number of wavelength supported equals n_w . The total number of possible candidate request for a single wavelength channel at any time are $n_s = n_f \times n_w$. The switch is using wavelength converter pools shared among individual fiber links called a shared-per-link architecture. As arrival rate to all output links is considered to be symmetric, therefore any link termed here as tagged link can be used to analyze the blocking behaviour of the each input channel acting as source is supposed to produce pure chance type II traffic (Iversen 2005). The source is called an on-off source and may be represented by a Markov chain as shown in Figure 2. In this case, when a packet/burst finds an output channel, the source is busy in completing the transmission until packet is fully transmitted and source becomes free.

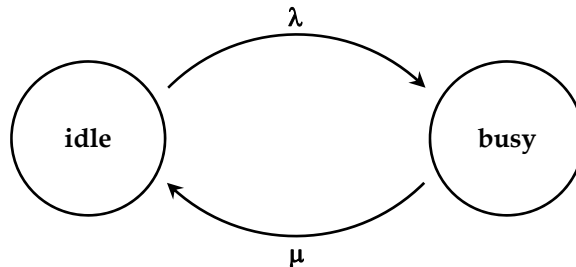


Figure 2: State Diagram for an Input Wavelength which changes between two States

We used the standard definitions to explain the parameters we will use in our analysis as follows (Iverson2005).

call intensity per idle input wavelength:	λ
mean service time (packet/burst length):	$1/\mu$
offered load per idle input wavelength:	$\beta = \lambda/\mu$
offered load per input wavelength:	$\alpha = \beta/(1+\beta)$
total offered traffic:	$A = s\alpha = s\lambda/(\lambda+\mu)$
total carried traffic:	Y

For the curves we use an additional normalization (JVirtamo2007) as given by following equation for offered load

$$A = n_s \cdot \frac{\lambda}{\lambda(P_c) + \mu}$$

Where P_c is the call blocking at tagged output link.

Two models we want to analyze here are: **i) Lost call cleared model:** This assumes that the bursts blocked at input wavelengths never reach to output wavelengths and cleared from the system without taking any time, **ii) Lost call delay dropped model:** is a modification of standard Engset assumptions. The blocked bursts never reach to the output, however, they cause blocked input wavelengths, in the sense that a burst is not assumed to be cleared from the system immediately but take time equal to its length in time. More precisely, the source generating the bursts is blocked generating new bursts for the amount of time a burst is being dumped at an input wavelength.

We may use the standard definitions of time, call and traffic blocking for comparison between blocking behaviours of above mentioned models. Time blocking is the ratio of time the system is blocked to the total time. Call blocking is the ratio blocked calls to total call while traffic blocking is the ratio of load blocked from reaching at the output of the system under consideration to the total offered load. In the next section, we will model an OBS node with shared wavelength under two assumptions mentioned above i.e. lost call cleared model and lost call dropped model.

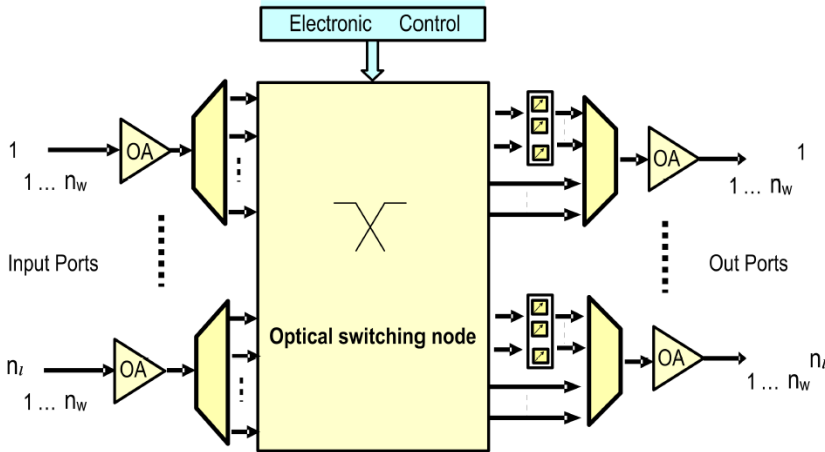


Figure 2: Node Architecture with a Shared Converter Pool per Output Link

4) ANALYTICAL MODEL

Architecture given in the last section can be taken as an Engset loss systems with limited number of customers i.e. the number of input wavelength channels. The system is then analyzed under assumptions of lost calls cleared and lost calls delay dropped.

Taking the first assumption, the system can be understood by a simplified model of the system shown in Figure 3 (a). We can use a bi-dimensional CTMC: (i, j) to model the working of such a loss system. The states are shown in Figure 3 (b). A state (i, j) represents the number of busy wavelengths i : $0 \leq i \leq n_w$ and the number busy wavelength channels j : $0 \leq j \leq n_c$. The arrival rate is state dependent and different rates are shown in Table 1. More the number of customer busy in the system less is the arrival rate as in standard Engset model. However, rate of occupation of wavelength along with wavelength converters is calculated assuming that more the busy channels the more is the probability that an incoming burst on a particular wavelength will not find the required wavelength at the output. This is catered by taking the ratio of busy wavelength channels to the total channels into account. Now right most states show the system where all wavelengths are busy. And the top most states show the blocked system due to unavailability of wavelength converters. Here the ratio of busy wavelength channels to total channels is used as system may not be fully blocked as wavelength channels are still available but wavelength converters are not available. We define the vector $\mathbf{P} = [p_0 p_1 p_2$

...] and transition rate matrix Q . Then we can use $PQ = 0$ to calculate the steady state probabilities of different system states under the normalization condition given below.

$$\sum_{i=0}^{n_w} \sum_{j=0}^{n_c} p_{i,j} = 1 \tag{3}$$

We use following performance measures to analyze the blocking behaviour of the system.

Time blocking: Its the ratio of time output wavelength channels are blocked to the total time. We can calculate by the ratio of time system is in blocked state to the total time which is normalized to 1. The relationship is given below:

$$P_t = \sum_{k=0}^{n_w} p(n_w, k) + \sum_{k=n_w}^{n_w-1} p(k, n_c) + \left(\frac{k}{n_w}\right) \tag{4}$$

Call blocking: We calculate the call blocking by taking the ratio of the number of customer arrived when all output channels were blocked to the total number of customers. This is given by:

$$P_c = \frac{\sum_{k=0}^{n_w} p(n_w, k)(n_s - n_w)\lambda + \sum_{k=n_w}^{n_w-1} p(k, n_c) * \left(\frac{k}{n_w}\right)(n_s - k)\lambda}{\sum_{j=0}^{n_w} \sum_{i=0}^{n_w} p(i, j)(n_s - i)\lambda} \tag{5}$$

Traffic blocking: This is defined by the load not carried to the output wavelength channels to the total offered load to the system and can be calculated as given:

$$P_t = \frac{A - Y}{A} = \frac{n_s \frac{\lambda}{\lambda + \mu} - \sum_{j=0}^{n_w} \sum_{i=0}^{n_w} p(i, j)}{n_s \frac{\lambda}{\lambda + \mu}} \tag{6}$$

Table 1: Transition Rates for CTMC with Engset Traffic in Figure 3

Current State	Next State	Transition Rate
(i, j)	$(i + 1, j)$	$\frac{(n_s - i)(n_w - i)\lambda}{n_w}$
(i, j)	$(i + 1, j + 1)$	$\frac{(n_s - i)(i)\lambda}{n_w}$
(i, j)	$(i - 1, j)$	$(i - j)\mu$
(i, j)	$(i - 1, j - 1)$	$j\mu$

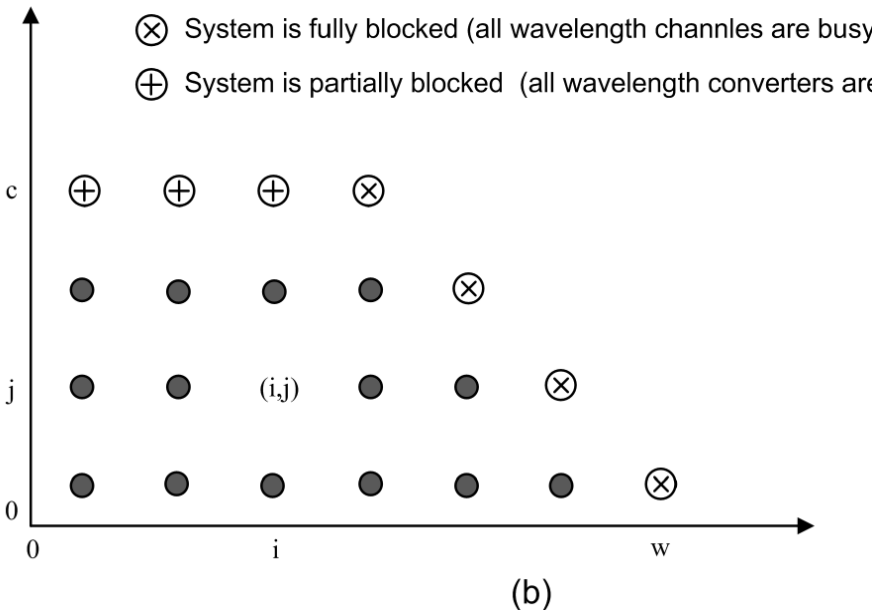
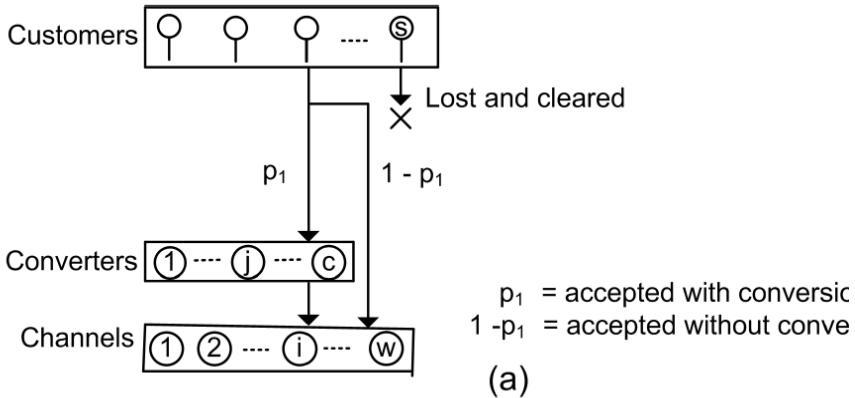


Figure 3: (a) Loss Model (b) State Diagram: $0 \leq i \leq n_w$, where n_w : Channels per Link, $0 \leq j \leq n_c$, where n_c : Converters per Link.

The second model we defined as lost call delay dropped model can be easily understood by extending our previous lost model as shown in Figure 4 (a). Now we assume virtual servers at the input catering the blocked input wavelengths. So the total time system is in blocked mode is modified now as its not only blocked due to blocked output but also due to the input wavelength channels which are busy in dumping blocked bursts. This means that if input channels are busy in dumping blocked burst no new burst can generated even if some output channel become free during that time. The CTMC (i, j, k) is three dimensional where $k: 0 \leq k \leq n_s - n_w$ represents the number of virtual channels busy in dumping dropped bursts at input of the system. The state diagram Fig. 4 (b) is self explanatory and the modified arrival rates are shown in Table 2.

We may use the following normalization condition to solve the system of balanced equations $PQ = 0$.

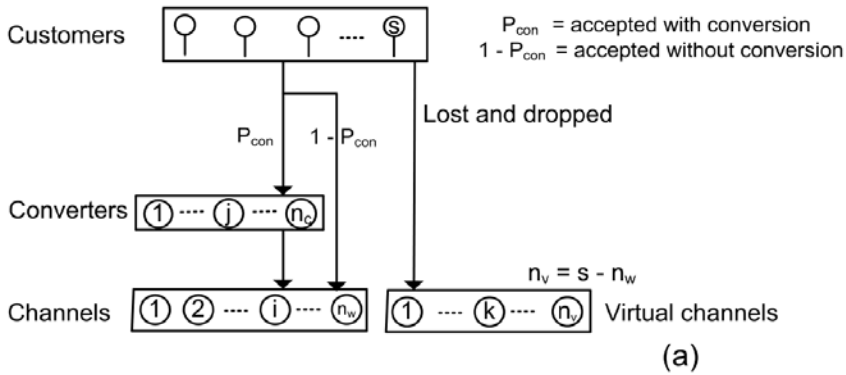
$$\sum_{i=0}^{n_w} \sum_{j=0}^{n_c} \sum_{k=0}^{n_s-n_w} p_{i,j,k} = 1 \tag{7}$$

The time blocking can be calculated again by taking time the system is in blocked states given by:

$$P_b = \sum_{j=0}^{n_c} \sum_{k=0}^{n_s-n_w} p(n_w, j, k) + \sum_{i=n_c}^{n_w-1} \sum_{k=0}^{n_s-n_w} p(i, n_c, k) * \left(\frac{i}{n_w}\right) \tag{8}$$

Traffic blocking is calculated by:

$$P_t = \frac{A - Y}{A} = \frac{n_s \frac{\lambda}{\lambda + \mu} - \sum_{i=0}^{n_w} \sum_{j=0}^{n_c} \sum_{k=0}^{n_s-n_w} p(i, j, k)}{n_s \frac{\lambda}{\lambda + \mu}} \tag{9}$$



- \otimes System is fully blocked (all wavelength channels are busy)
- \oplus System is partially blocked (all wavelength converters are busy)
- \nearrow Occupation of virtual channels on arrivals

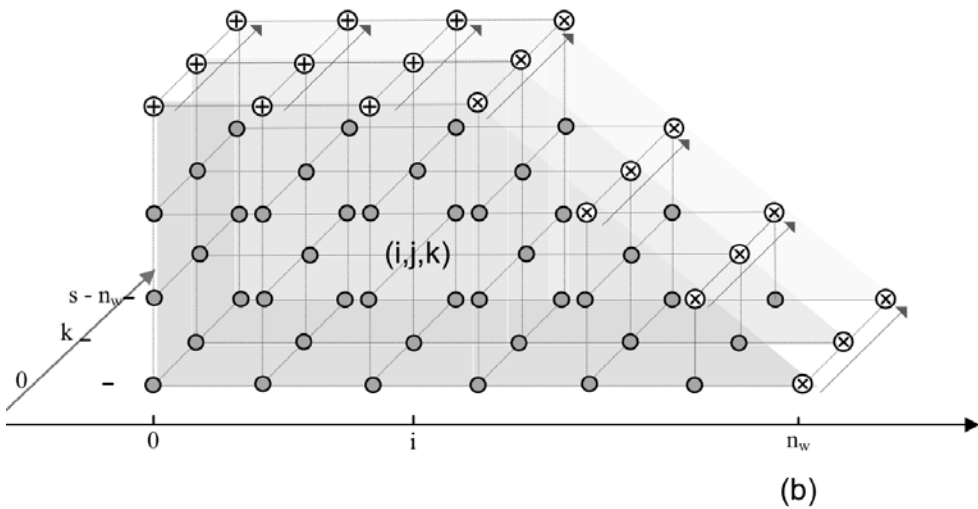


Figure 4: (a) Loss call delay dropped model (b) State diagram for the model

Table 2: Transition Rates for CTMC in Figure 4.

Current State	Next State	Transition Rate
(i, j, k)	$(i + 1, j, k)$	$\frac{(n_s - i - k)(n_w - i)\lambda}{n_w}$
(i, j, k)	$(i + 1, j + 1, k)$	$\frac{(n_s - i - k)(i)\lambda}{n_w}$
(n_w, j, k)	$(n_w, j, k + 1)$	$(n_s - i - k)\lambda$
(i, n_c, k)	$(i, c, k + 1)$	$\frac{(n_s - n_c - k)(i)\lambda}{n_w}$
(i, j, k)	$(i - 1, j, k)$	$i\mu$
(i, j, k)	$(i - 1, j - 1, k)$	$j\mu$
(i, j, k)	$(i, j, k - 1)$	$k\mu$

And finally we take the ratio of blocked calls to the total number of calls to find out the call blocking as given by:

$$P_c = \frac{\sum_{j=0}^{n_c} \sum_{k=0}^{n_s-n_w} p(n_w, j, k)(n_s - n_w - k)\lambda + \sum_{i=n_c}^{n_w-1} \sum_{k=0}^{n_s-n_w} p(i, n_c, k) * (i/n_w)(n_s - i - k)\lambda}{\sum_{i=0}^{n_w} \sum_{j=0}^{n_c} \sum_{k=0}^{n_s-n_w} p(i, j)(n_s - i - k)\lambda} \tag{10}$$

5) NUMERICAL RESULTS

In this section, we evaluate the models formulated in the previous section. Important numerical results are presented to compare the blocking behaviour of a non-blocking OBS node with shared wavelength converter pool under lost call cleared model and lost call delay dropped model.

In Fig. 5, load is fixed at 80 percent; two different conversion ratios are used to plot the blocking behaviour of node with varying number of input fibers. It is clear that with the increasing number of input fibers time, blocking is decreased in both cases and while call blocking and traffic blocking show the increasing behaviour with the number of increasing input fiber for 100 percent conversion ratio. However, if the conversion ratio is reduced to 50 percent, call blocking for lost call cleared model fail to capture the true or expected blocking behaviour. However, the traffic and call blocking show the expected behaviour. As with increasing number of input fibers the variance of input load increases and

blocking of system should show an increasing behaviour. However, it is clear that time blocking in both cases fail to capture this behaviour as it only taking the time output of the system is not available. However call and traffic blocking capture this behaviour in conversion ratio equal to 100%, but if conversion ratio is reduced to 50 percent even call blocking does not show the expected behaviour. Traffic blocking actually take into the account the load which cannot be forwarded due to blocked input channel, therefore it is the true blocking measure of the system and successful in capturing actual system behaviour for all conversion ratios. The behaviour of the system can't be captured by time blocking here as it is not true full access lost system and due to the shared converter behaviour time and call blocking both should not be used for evaluating the response of the system as also proved by (Overby 2005). From Figure 6 to 10, it is clear that for lost call cleared model $P_e \geq P_c \geq P_t$ and also for lost call delay dropped model $P_e \geq P_c = P_t$. In Fig. 6, we have used just 20 input wavelengths, with conversion ratio of 100 percent. The same is repeated with conversion ratio of 50 percent in Figure 7. In Figure 8 and Figure 9, number of input wavelengths has been increased to 100. It is very clear in all above cases the time blocking and call a are overestimating the blocking rate of the system and traffic blocking is true measure which should be used.

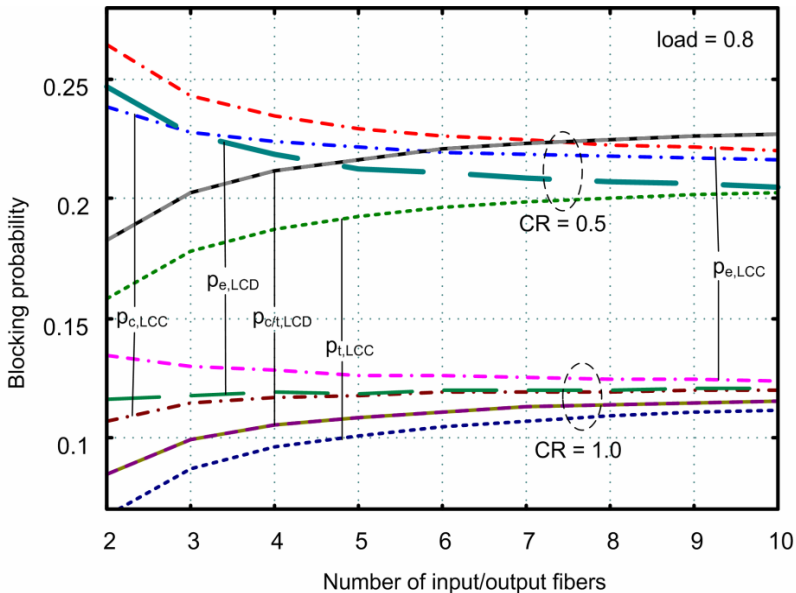


Figure 5: Blocking Probability Vs. the Number of Input/Output bers with CR = 0.5, 1.0, nw = 10, ns = 100, and Load per ber = 0.8 at a Tagged Output Link

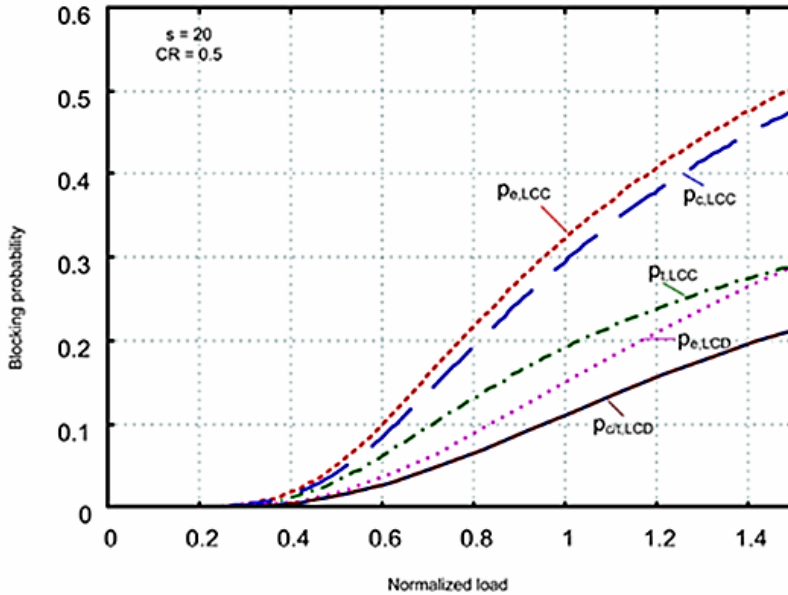


Figure 6: Blocking Probability Vs. the Normalized Load with $nw = 10$, $ns = 20$ and $CR = 0.2$ at a Tagged Output Link

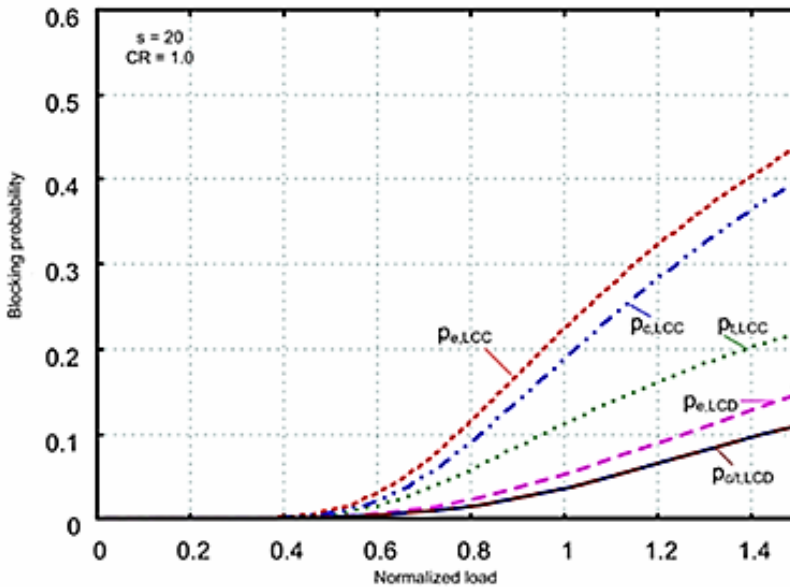


Figure 7: Blocking Probability Vs. the Normalized Load with $nw = 10$, $ns = 20$ and $CR = 1.0$ at a Tagged Output Link

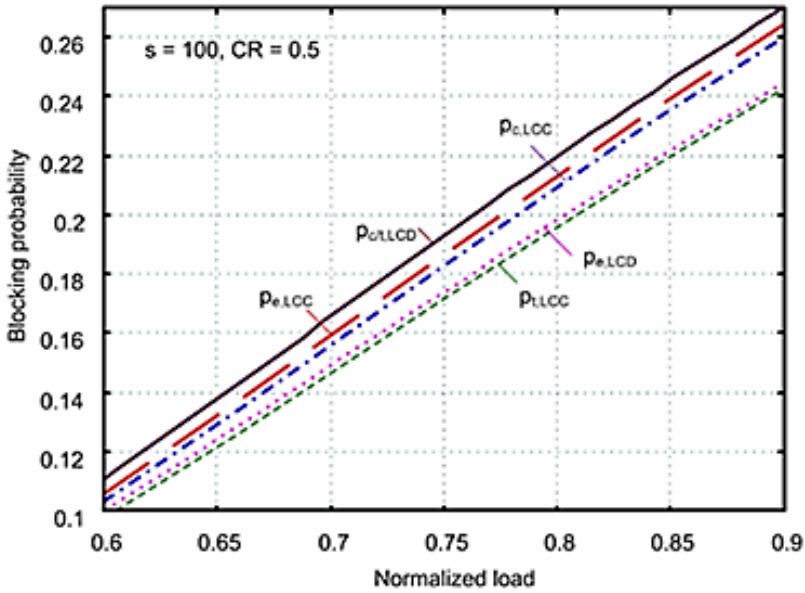


Figure 8: Blocking Probability Vs. the Normalized Load with $w = 10$, $s = 100$ and $CR = 0.5$ at a Tagged Output Link

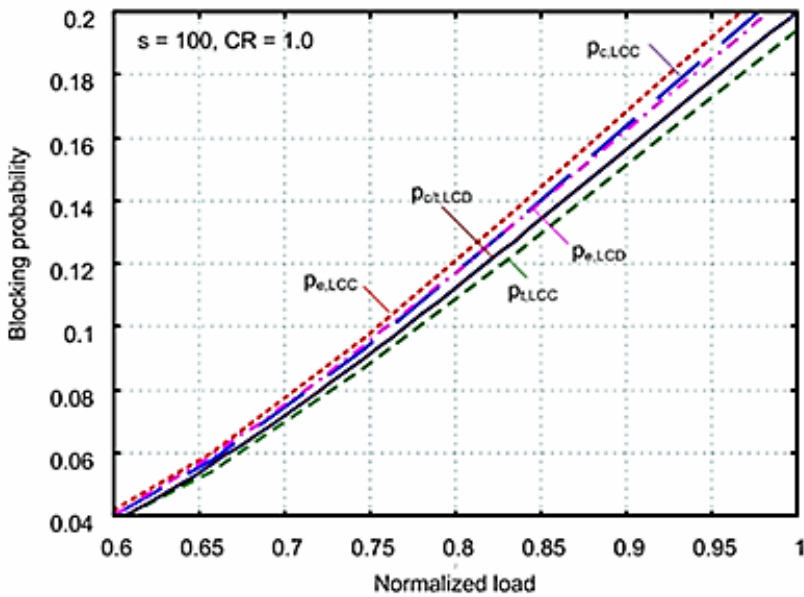


Figure 9: Blocking Probability Vs. the Normalized Load with $w = 10$, $s = 100$ and $CR = 1.0$ at a Tagged Output Link

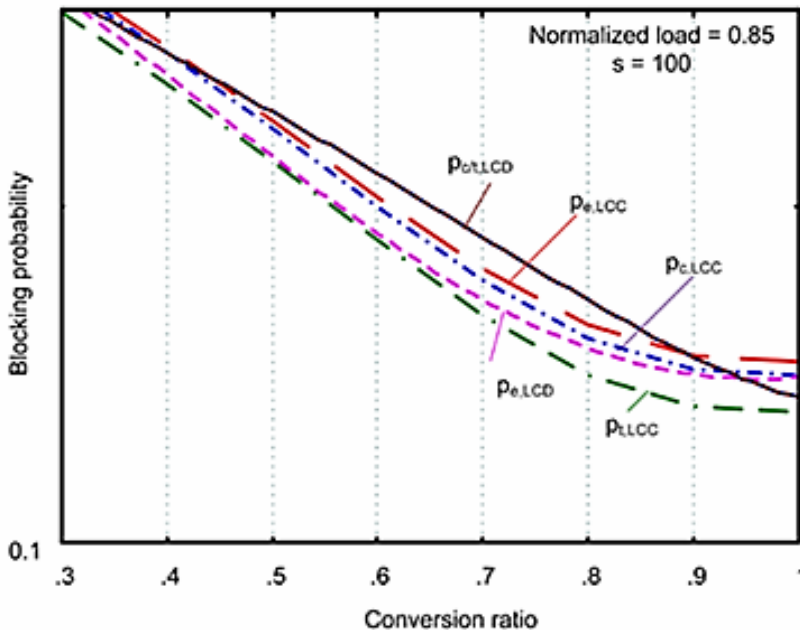


Figure 10: Blocking Probability Vs. the Conversion Ratio (CR) with Load = 0.85, $s = 100$ and $w = 10$ at a Tagged Output Link

6) CONCLUSIONS

It has been shown that for all-optical burst/packet switching nodes with small or medium port counts; Engset if applied readily will over estimate the blocking probability and a modified Engset will give more accurate results. The affects in blocking probability are not ignorable if compared the basic and modified arrival models. The extensive results have shown to prove the affects of shared wavelength conversion degree on the blocking behaviour of the switching nodes.

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