Traffic and performance analysis of optical packet/burst assembly with self similar traffic

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ABSTRACT

In this paper analytical and simulative study of optical packet/burst assembly in the presence of self similar input traffic is presented. The influence of the main assembly parameters is studied by simulation for timer and size-based aggregation strategies. Analytical model is proposed to represent the average traffic on optical link with the aim to evaluate system performance. Comparisons with simulation prove that the model is well suited to catch the loss system behaviour.

Keywords: WDM, Optical Packet/Burst Switching, Packet assembly, Traffic model, Simulation

1. INTRODUCTION

Optical packet-switched (OPS) and optical burst-switched (OBS) networks have been considered with growing interest in the last decade as a long and medium-term solution for core networks to carry the expected increased traffic generated by high capacity local and metropolitan area networks. Many papers presented technological issues and discussed the potential benefits of the adoption of optical burst and packet switching using the huge bandwidth of the DWDM transport with fine granularity and considerable flexibility [1-6].

In order to alleviate the switching overhead in the high-speed optical switch, both OPS and OBS apply a large data frame for data transmission. Correspondingly, the edge node has to first classify the data traffic coming from the client networks (Ethernet, IP, …) into different forward equivalent classes (FEC), and then assemble data of the same FEC in optical data frames. The assembly procedures can substantially change the traffic characteristics so and have an significant impact on the network performance, which will be closely looked at in this paper. Since the assembly function means the same thing for OPS and OBS, for brevity we do not distinguish them in the following context unless otherwise indicated explicitly. The optical data frame of OPS/OBS will be referred to as optical burst uniformly.

A number of publications have been contributed to the traffic characterization and performance impact of the burst assembly. The statistics for the size and interarrival time of optical bursts from the assembly are studied in [8-9]. The impact of the assembler on the self-similarity of the data traffic is inspected in [10-11]. [12] discusses performance issues with respect to blocking probability, and discovers that the Poisson approximation of the optical burst traffic provides an upper bound for blocking probability.

In our paper, through extensive simulation and analysis, the performance impact of different assembly parameters is inspected. We find the performance behaviour in the edge node can be well captured by an on-off model of the optical burst traffic in the typical network operation scenarios.

The paper is organized as follows. In Section 2, the observed system model is described and the applied self-similar traffic model is introduced. In Section 3, we analyze the influence of the assembly on the offered traffic load and propose the performance model. Simulation results as well as analytical estimations are presented and explained in Section 4. Finally, Section 5 draws the conclusions of the work.

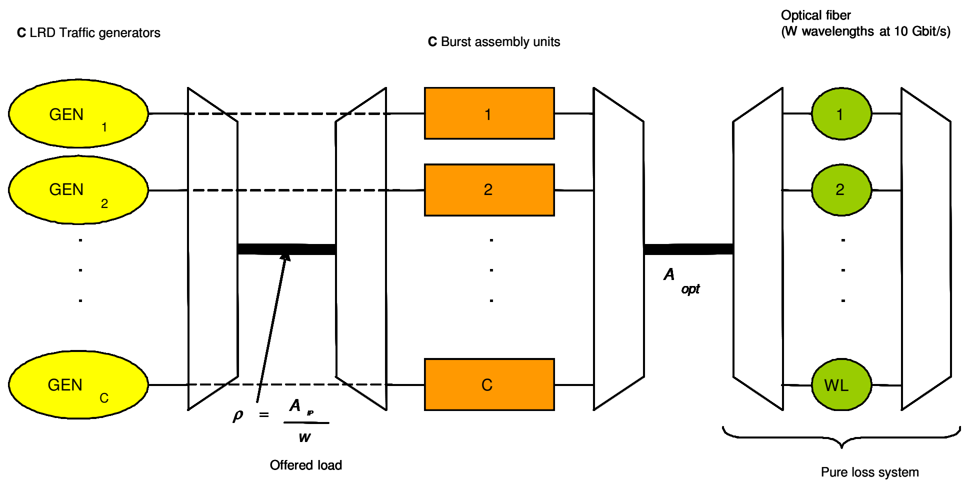

Figure 1 – The burst assembly system

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2. SYSTEM AND TRAFFIC MODEL

The system under study is the assembly process at the optical network edge which is sketched in Fig. 1.
It is composed of three main blocks: traffic generators, optical burst assembly units and DWDM optical network link.
Totally C traffic generators are used, with each of them generating aggregate self-similar IP traffic for one FEC class according to M/Pareto model as applied in [11]. With M/Pareto model, IP packets are segmented from data transmission sessions that arrive following a Poisson process and have the session size distribution conforming to a heavy-tailed Pareto distribution. The main parameters characterizing an M/Pareto traffic model include:

- IPmax : the maximum length of the IP packets used to fragment each data session, for our purpose 1000 Bytes;
- PpF: the mean session size normalized by the maximum IP packet length;
- H: the Hurst parameter that represents the degree of self-similarity and from which the shaping parameter of the Pareto distribution can be derived. In the simulations, H is set to 0.7.
- Ba: the access link speed (100Mbps), which determines the interval between back-to-back packets of the same session.
- A_{IP}: the total offered traffic of IP traffic in the unit of Erlang.

At the stage of burst assembly, IP packets are classified according to their destination address and QoS class and distributed into correspondent assembly queues. With respect to the assembly schemes, we suppose there is always a timer bounded to an FEC assembly queue to constrain the assembly delay. As for the burst size, two cases are distinguished: unbounded size and fixed size. With unbounded size there is no padding overhead, while fixed burst length can bring some efficiency in performance and implementation. The following parameters are defined for the burst assembly:

$TOF = \frac{t_{out}}{IAT}$ time out factor, given by the ratio between the assembly time out t_{out} and the mean packet inter-arrival time of each FEC IP flow (IAT). In our simulations, each FEC IP flow has the same IAT.

$BSF = \frac{BS}{IP_{MAX}}$ burst size factor, given by the ratio between the fixed burst size (BS) and the maximal IP packet size.

The third stage is a model of a WDM transmission link with w wavelengths and 10 Gbps per wavelength.

3. TRAFFIC CHARACTERIZATION AND PERFORMANCE ANALYSIS

To analyze the loss probability in the edge node, the third stage can be modelled by a pure loss system where multiple servers represent the wavelength channel bundle. Correspondingly, the number of servers equals the number of wavelengths w. The incoming traffic to the loss system is multiplexed by departure flows from the C assembly queues.
The offered load to the system A_0 equals to A_{IP} in the case of unbounded burst size. If the fixed burst size is used, A_0 is greater than or equal to A_{IP} since padding can be added by the assembly. Here, the filling of burst depends on the relation between TOF and BSF. Following asymptotic operational regions can be investigated:

- BSF>>TOF where the assembly time out dominates the assembly of burst;
- BSF<<TOF where all bursts leave because they are full.

In the first case, the average number of IP packets in a burst can be derived as n=$\lambda_{IP,FEC}$ t_{out} +1 where $\lambda_{IP,FEC}$ =1/IAT [6].
This leads to n=TOF+1 directly. Therefore, it holds that:

$$A_0 = C\frac{\lambda_{IP,FEC}}{TOF+1}\frac{BSF*IP_{MAX}}{B} \qquad \text{for} \quad \text{TOF<<BSF} \tag{2}$$

Here, B is the service capacity of one server and equal to 10 Gbps.
In the second case, since the bursts are mostly full, there is $A_0 \approx A_{IP}$ and $n \approx BSF$. Then approximately

$$A_0 = C\frac{\lambda_{IP,FEC}}{PSF}\frac{BSF*IP_{MAX}}{B} \qquad \text{for} \quad \text{BSF<<TOF} \tag{3}$$

It is now useful to find the intersection point of the two operational regions by equating expression (2) and (3). It results in BSF=TOF+1 that can be approximately considered as the delimiting operational point where most assembled bursts turn to be completely filled.
As A_0 and number of servers w are available, Erlang-B formula can be applied to calculate the burst loss probability as an upper bound [12]. However, this is generally too conservative for small and medium number of FEC classes.
Actually, as long as the load contribution from each FEC flow, i.e., A_0 /C is less than 1 and the aggregation degree of the assembly is large (i.e., with large TOF or BSF), it becomes unlikely that a burst inter-departure time from an assembly queue is smaller than the burst transmission time of the foregoing burst. So, the optical burst traffic of each FEC can be modelled by a fluid on-off flow with the ON period corresponding to the transmission time of one burst on the wavelength channel. Traffic rate in each ON period is constant and equal to the transmission rate of a wavelength channel. The interarrival time of ON-periods corresponds to the burst inter-departure time from an assembly unit. For self-similar IP traffic, packets tend to arrive in clusters (Joseph effect) [13]. As a result, the departure burst traffic is likely to have large burst size (pure time-out assembly) or clusters of fixed burst size with small interarrival time (assembly with fixed burst size). Therefore, a general on-off traffic model [14] can be applied, which is parameterised by two parameters p and r. p is the proportion of time spent in the ON period, which is equal to A_0/C. r is the constant

traffic rate in the ON period. The loss probability of the aggregated traffic multiplexed by C such on-off flows can be calculated according to the method of effective bandwidth (Equation 2.9 and 3.11 in [14]).

4. PERFORMANCE EVALUATION

The results of performance evaluation will be given in this section.

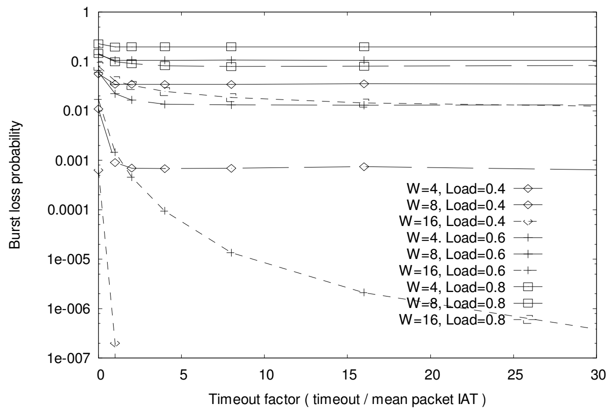

Figure 2 –Burst loss probability as a function of TOF for different values of the offered load and number of wavelength channels, C=10

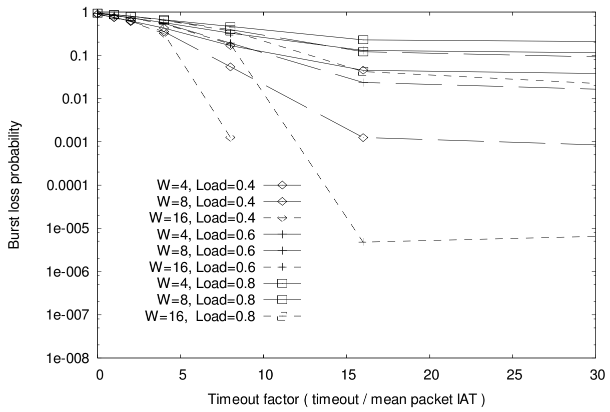

Figure 3 – Burst loss probability as a function of the TOF for different values of the offered load and number of wavelength channels, C=10, BSF=16

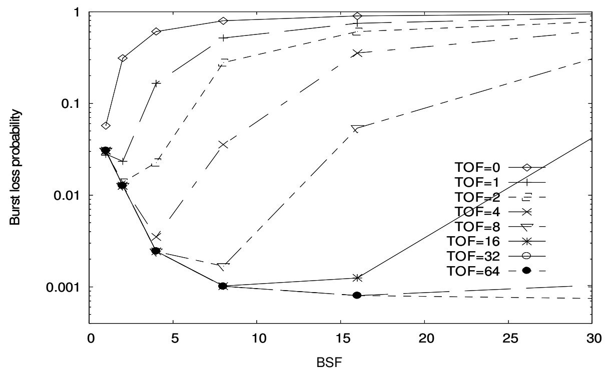

Figure 4 – Burst loss probability as a function of the BSF varying the TOF as a parameter; C=10, w=8, ρ=0.4.

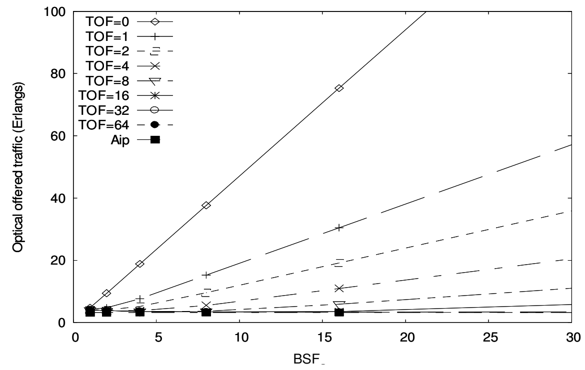

Figure 5 – Optical offered load A_0 as a function of BSF varying TOF. A_{IP} is also shown as a reference.

In Fig. 2 performance of burst traffic assembled by algorithm based on the pure time out strategy is presented. C=10 here. It can be seen how the aggregation process can improve the performance in terms of burst loss probability. In most cases, the loss probability decreases at the beginning fast with the increase of timeout and then becomes stable. For the cases of 16 *w* (load=0.4 and load=0.6), the number of wavelengths are greater than the number of burst flows. At the same time, the traffic load contributed by each flow is less than 1 (0.64 and 0.96 respectively). In case the number of servers is larger than the number of on-off flows and the peak rate of the on-off traffic is equal to the service rate, the loss probability turns out to be 0. Therefore, with increasing timeout each burst flow asymptotically degrades to an on-off flow and the loss probability goes down continuously to zero. Also note that in the case of w=16 and load=0.8, the load on each flow is 1.28 and the burst flow cannot be modelled as on-off flow any more.

In figure 3 the burst size is fixed. Loss probability is plotted as a function of the TOF, and when TOF<BSF performance gets better with TOF due to increasing aggregation and a better filling efficiency, whereas when TOF > BSF the assembly algorithm works almost always by payload filling and we could assume that time out never expires. In the latter case the assembly procedure is not affected by TOF and performance saturates at values depending on BSF (lower values for higher BSF).

This comparison shows that there is an optimum design choice for TOF and BSF, i.e. when TOF is about equal to BSF loss probability has a minimum. This is very close to the delimiting operational point derived in Section 3. To better explain this we show the burst loss probability as a function of TOF and BSF with BSF and TOF as parameters, respectively. Fig. 4 shows the burst loss behaviour as a function of the BSF. It is clear that the optimum of each curve falls around the point of BSF=TOF+1. The curve TOF=64 has the minimal loss probability among all due to resulting largest aggregation level. The minimum loss probability in Fig. 4 is very close to that of the correspondent curve (w=8, Load=0.4) in Fig. 2. This indicates that same performance model can be applied for both unbounded burst size and fixed size schemes as long as the aggregation level is large enough. Similarly, for the reason of increasing aggregation level, most curves decrease first with the increasing BSF. Beyond the optimum point, the impact of the padding overhead begins to be serious. This is confirmed by Fig. 5 that represents the offered traffic A_0 as a function of the BFS varying the TOF. For given TOF, A0 increases with BSF, which can lead to higher loss probabilities as shown in Fig. 4. In Fig. 6, the analytical results of the loss probability are compared with the simulation results with respect to different offered load. Here C=10 and w=8. For simulation only the unbounded burst size case is considered and TOF=8. From Fig. 2 it can be seen that at TOF=8 the loss probability already converges, so it is a large enough aggregation level for the application of on-off source model. For analysis, we consider the Erlang-B formula and the effective bandwidth method based on the multiplexing of on-off model as described in Section 3. It is seen that for small loss probability, the effective bandwidth provides quite good estimations. However, for large loss probability it works not well. This is because that effective bandwidth method is developed on the basis of large deviation theory which is oriented for the estimation of rare events. In the real application where the goal loss probability is in the order of 10^{-4}, effective bandwidth method can play an important role.

5. CONCLUSIONS

In this work we study the burst traffic characteristic and burst loss probability in the edge node of OBS/OPS networks with self-similar IP traffic. The basic system behaviour of the assembly is analyzed and simulated. The relative relation between timeout and fixed burst size is discovered which can be used as a reference for the optimal system design. We propose the multiplexing of on-off sources to model the optical burst traffic. This model can not only explain the simulative system behaviour very well, but also lead to tight estimation of loss probability in the practical interested area.

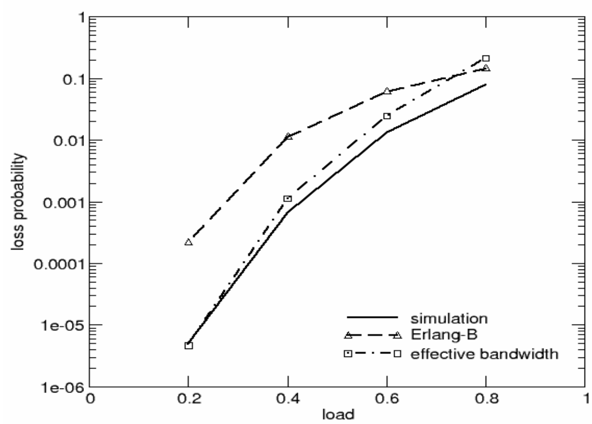

Figure 6 – Comparison of analysis results as a function of the offered load for C=10, w=8, TOF=8

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