

Optical Packet Ring Optimization for the Assessment of Tradeoff between QoS and Design Cost

Bogdan Ušćumlić, Slavica Boštjančič Rakas

Department for Telecommunications

Institute Mihailo Pupin, University of Belgrade

Belgrade, Serbia

bogdan.uscumlic@pupin.rs, slavica.bostjancic@pupin.rs

Abstract—Many methods for finding the optimal design of an optical packet switching ring network are without the performance guarantees, leading to the unexpected network behavior in terms of the QoS performance that network offers to its clients. The inter-dependability between the network QoS performances and the cost optimal design of an optical packet switching ring with a single tunable transmitter and multiple fixed receivers per node, are studied in this paper. First, a method for the cost optimal and stable dimensioning of the ring, focusing on wavelength and receiver costs, is introduced. The method is called the “packet aware design”, as it incorporates the packet properties of the network traffic, in order to offer the insertion queue stability, as an added value. Then, by performing the computer simulations on a set of optimal network configurations, the tradeoff between the QoS performances and the design cost is identified and quantified. The results show how the packet latency depends on the increase of the wavelength utilization factor and the traffic amplitudes. It is demonstrated that the lower node loads result in a better performance, at the same level of the wavelength utilization. Finally, the maximum wavelength utilization factor, for which a ring loaded with the uniform and symmetric traffic achieves the satisfactory latency performance, is found.

key words—metropolitan rings; optical packet switching; optimal dimensioning; packet latency; optical transparency; WDM;

I. INTRODUCTION

In this paper, an optical packet switching ring, designed for metro area, based on the WDM technology, use of tunable lasers and multiple wavelength receivers at each node, is considered. This network [1] was first developed within the French ECOFRAME project (2007-2009) lead by Alcatel-Lucent, and including French academic institutions and SMEs. Other optical packet rings architectures were previously studied by several research projects including HORNET [2], RINGO [3], FLAMINGO [4], DAVID [5] and DBORN [6]. The extensive research of the optical packet switching rings is due to the fact that optical packet rings can merge optical transparency with fine granularity.

ECOFRAME rings provide optical transparency to transit traffic and can share sets of wavelengths among different destinations, while sources can transmit traffic on all wavelengths. The performance of a single-wavelength, unidirectional optical packet ring of type ECOFRAME is studied in [7], and the impact of WDM dimension on its

performance in [8]. In this paper the studied problem is the tradeoff between the quality of service that the ring delivers to its clients, if the ring is previously “optimally dimensioned”. An “optimal dimensioning”, or an “optimal design” of the ring is actually, its configuration, which shall be able to achieve the both: to support the input traffic demand, and to have the minimum cost in terms of the needed network resources. Here, for the dimensioning of the network, the so-called “packet aware design”, introduced originally in [9], is used, on which detailed explanations are given later. An important positive property of the packet aware design is that apart from offering a minimum cost configuration, it also offers a solution for the stability of the ring, so this is why the focus on this designing solution. If an optical network is optimally dimensioned, it still does not mean that it will offer a fair QoS performance to its clients (the entering traffic flows). In this paper, the focus is on the packet latency, and the ring configurations with good network performances are explored.

The reminder of the paper is organized as follows. The basic characteristics of the network in study are described in Section II. The Packet Aware Design is explained in Section III and the computer simulator used for performance evaluation of the network is introduced in Section IV. The numerical results are elaborated in Section V. Finally, the last section concludes the document.

II. THE ECOFRAME OPTICAL PACKET RING

The system is synchronized and the optical medium is accessed by the ECOFRAME stations called Packet Optical Add/Drop Multiplexers (POADMs), during the intervals of fixed length (time slots). The optical rings ECOFRAME use the WDM multiplexing and the optical containers of fixed size. There are two types of channels used in the ring: 1 control channel and approximately 40 data channels. The control channel transports the information concerning the optical containers of data channels, including the time slot status of data channels (a time slot can be either free or busy), the class of service of the optical containers and the information relative to the reservation mechanisms.

The principal characteristics of the ECOFRAME ring are the optical transparency of the transit traffic and the optical packet switching. The optical transparency helps in reducing the size of stations by simplifying the hardware installed at each location and consequently, it reduces the cost of the

consumed energy, an important component of OPEX. On the other hand, the packet level granularity of the switching makes the bandwidth utilization more efficient, which is another notable advantage of this technology. Each station in the ring is equipped with a tunable transmitter and a number of fixed single-wavelength receivers, each of which receiving traffic on a single predefined wavelength. Consequently, an ECOFRAME station can insert only a single packet during a time slot, but it is capable to extract several packets during a time slot, at destination. The receivers that operate at the same part of the bandwidth can be used by several destinations.

III. PACKET AWARE DESIGN OF ECOFRAME RING

The dimensioning of the optical packet ring consists in “mapping” each source-destination flow (given by the input traffic matrix) into the wavelengths so that the cost of the used resources would be at the minimum. ECOFRAME ring configuration is defined by the active wavelengths in the ring, and the receivers at each station.

The dimensioning goal is to minimize the total cost, i.e. to find a configuration at the optimal cost. The total cost is equal to the sum of costs of wavelengths and receivers. The cost of a wavelength (C_w) can be estimated to 1/40 of the cost of a dark fiber. The cost of a single-wavelength receiver (C_r) is approximately equal to the cost of a transmitter connected to a 10GigE port. In this work, the result from [10] which showed that $C_r/C_w \approx 0.1$ is used. Thus in the experiments, $C_r = 0.1$ and $C_w = 1.0$, without units. Consequently, in the diagrams, the design cost is also given without units.

The stability problem when designing the optical packet switching network appears because the packet nature of the traffic is not taken into account, so the packets can experience an unbounded delay when crossing the network. This problem has been addressed in [9], and as a result “the packet aware design (PAD)” dimensioning is obtained. In this paper the PAD dimensioning is used for configuring the network.

In PAD, the packet-based nature of the traffic is taken into account by considering the queues at the nodes. At a given node i , the queue of wavelength w stores all the packets to be transmitted to the nodes that are equipped with receivers on that wavelength, i.e., packets arriving in a node are classified in separate queues according to the wavelengths on which they are routed. Packets generated locally at the nodes are assumed to arrive following a Bernoulli process. The Bernoulli arrival of the packets to the queue of wavelength w in node i has an average rate λ_i^w . The packets are transmitted when a time slot on w is free, and the transmission time of a packet is one time slot. When packets on several wavelengths are available for the transmission, the next packet for transmission is chosen according to the Oldest Packet First policy. After the transmission, it is assumed that the next time slot is free with probability μ_i^w and is busy with probability $(1 - \mu_i^w)$, also following a Bernoulli process. Based on such assumptions, the queue is modeled as a Geo/Geo/1 queue with arrival rate λ_i^w and service rate μ_i^w . The queue load is $\rho_i^w = \lambda_i^w / \mu_i^w$. To ensure the stability and a bounded queueing delay, in PAD the queue load is limited by the *wavelength utilization factor* γ :

$$\rho_i^w = \lambda_i^w / \mu_i^w < \gamma, \forall i, \forall w, \quad (1)$$

with $\gamma \in (0, 1)$. A change of the parameter γ will directly affect the design cost of the ring, as γ defines the occupancy of the wavelengths. The Mixed Integer Linear Programming (MILP) formulation of PAD design is given in [9].

IV. SIMULATOR IN NS-2

For the simulations, the Network Simulator ns-2.31, enhanced with additional functions, developed to study the behavior of the ECOFRAME ring, is employed. The simulator obtained in such way is called ESOPE, which comes from ECOFRAME Slotted Optical PackEt ring simulator. More precisely, a new Medium Access Control (MAC) layer has been coded and added to ns-2.31. The simulator ESOPE is available online at [10]. The ring structure is coded in OTCL, while the MAC functionality (the new MAC class) is coded in C++. All simulation results are obtained at a confidence level of 95% and with a confidence interval of 10%. The confidence intervals are indicated in the figures.

To evaluate the performances in terms of QoS, the sum of the insertion and the extraction time, i.e. the **end-to-end packet latency**, is measured. The insertion process leads to delays, because of the queueing process of data packets prior to insertion to the ring. The extraction time is due to the fact that a given node may receive packets on several wavelengths, whereas it delivers them to the client layers at a rate equal to a wavelength rate.

V. NUMERICAL RESULTS

The current section contains the numerical results. All the results are for a 6-node ring, and for the uniform and symmetric traffic matrix, meaning that between every two nodes in the ring there is a connection of the same amplitude a (the value of traffic is normalized to the wavelength capacity). The traffic departing from a node is limited by the wavelength capacity, as it is supposed that each node has only 1 tunable transmitter.

The network configurations PAD are obtained by using the linear programming optimization software, and the presented results are optimal. The network performances are measured by the computer simulation with ESOPE simulator, and these results are obtained in two steps: 1) for a given traffic matrix and a given value of γ , the ring is first dimensioned by using the PAD method; 2) for such design, the network behavior is simulated by using the ESOPE simulator.

In Fig. 1, the dependence of the optimal design cost on the traffic amplitude a , for different values of the wavelength utilization factor γ , is presented. For increasing values of a , the overall design cost increases, as can be seen in Fig. 1. This is logical, as for the increased values of traffic, the overall number of resources (wavelengths and receivers) needed in the network increases. With the increase of γ , the design cost

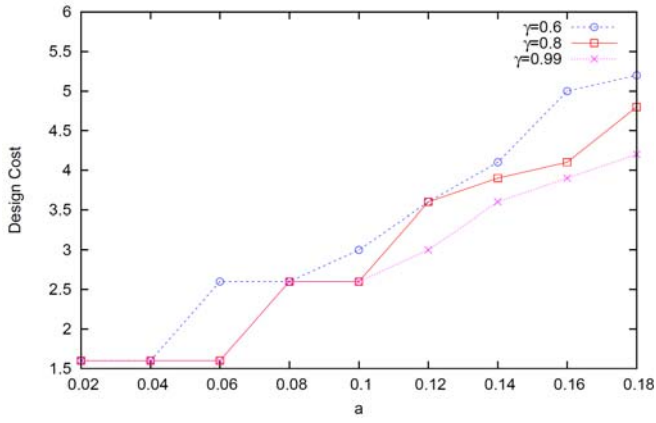


Figure 1. Design cost versus the traffic amplitude a , for different values of γ

decreases. This is also expected, as γ corresponds to the percentage of occupancy of a wavelength, so with the increase of γ , the number of wavelengths in the ring design increases. An interesting contribution of Fig. 1 is the quantification of the gain in cost for large values of γ : if γ is augmented from 0.6 to 0.99, the cost savings can go up to $\approx 39\%$ (achieved for $a = 0.06$). In other words, the choice of γ can highly impact the cost of the design, for the same traffic matrix.

For a fixed traffic amplitude ($a = 0.18$), the design cost and the mean latency of the traffic sent by a station, in a function of γ , are found in Figs. 2 and 3. Fig. 2 shows that the design cost, the costs of wavelengths and receivers decrease when γ increases. For higher values of γ , the wavelengths are filled more, so the number of needed wavelengths and receivers is smaller, i.e. the network configuration is cheaper. In this particular case (Fig. 2), the cost of wavelength remains the same for all values of γ i.e. the ring configuration cost decrease is due to the decrease in a number of receivers given by the optimal design. While the network configuration becomes cheaper, the network performances degrade with the increase of γ . The result in Fig. 3 confirms this and gives a quantification of this phenomenon. As one can see (Fig. 3), for the values of maximum wavelength load less than 0.64, the

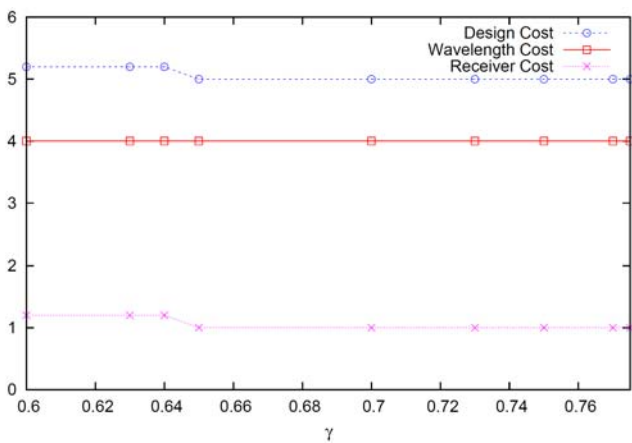


Figure 2. Design, wavelength and receiver cost versus the wavelength utilization factor γ

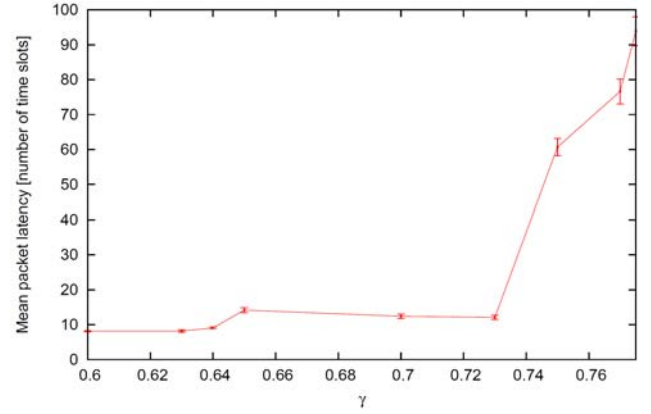


Figure 3. Mean insertion and extraction latency versus the wavelength utilization factor γ

mean latency of the traffic remains less (or around) than 10 time slots, which can be considered as a satisfactory performance. When increasing γ up to 0.73, the latency remains limited to 15 time slots. For larger values of γ the mean latency becomes too large, and its increase becomes similar to the exponential behavior.

Note that the curve in Fig. 3 is not strictly monotonous in all the points, which is not surprising, if one keeps in mind that each point in this diagram is obtained by the computer simulation for the optimal network design of a ring. The optimal network design defines the number and types of receivers at each node and the number of wavelengths used in the ring, so it can happen that although the design is obtained for a higher value of γ , the mean latency of the traffic is smaller, because of the complex impact that each network configuration has on the network performances. To summarize, Figs. 2 and 3 show the tradeoff between the network cost and QoS performance: for small values of γ , the network is more expensive, but its performance is better; when decreasing the design cost (for increased values of γ), the network becomes more sensitive to congestion, and its performances degrade.

To evaluate how the change in traffic amplitude affects the

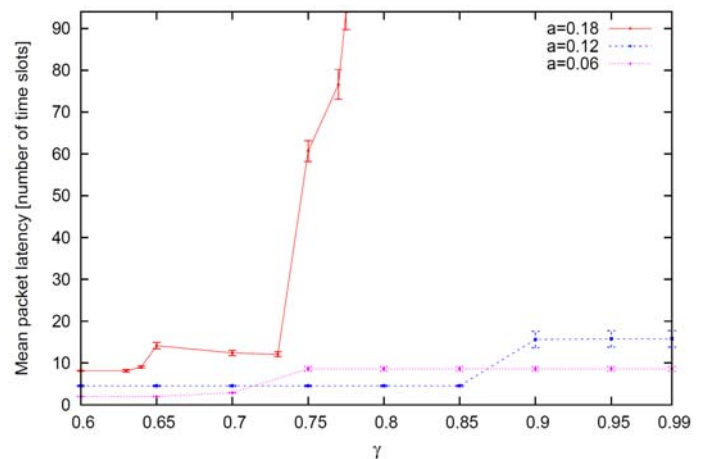


Figure 4. Mean insertion and extraction latency in function of the wavelength utilization factor γ , for different values of traffic amplitude a

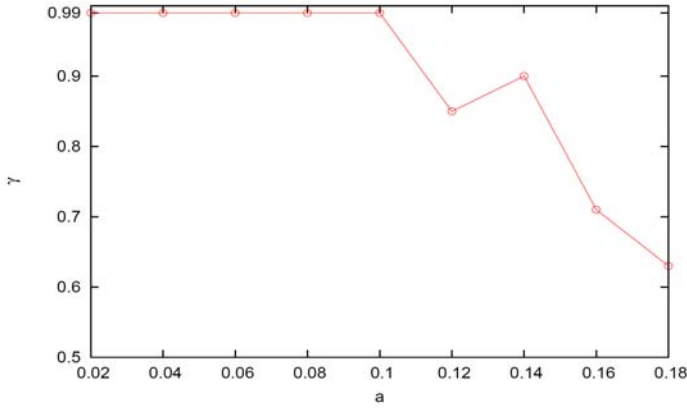


Figure 5. The wavelength utilization factor γ for which the mean latency of insertion and extraction is limited to 10 time slots

QoS performances of the network, a simulation where the traffic amplitude a is a parameter is conducted. The results are presented in Fig. 4. Obviously, the lower the traffic amplitude a , the better the latency achieved in the network. For instance, for $a = 0.06$, the mean latency is within 10 time slots in the entire range of γ . The congestion is unlikely to occur for smaller amplitudes, although the number of wavelengths in the ring is also decreased and the number of the routed connections between stations per wavelength is even increased, when compared to the higher amplitudes. It is because the overall traffic sent by a station is smaller and consequently, the ring is less sensitive to change of γ .

In the previous examples, the tradeoff between the traffic QoS level and the network cost has been identified and quantified. It would be very interesting to know, at which level of the wavelength utilization factor γ , the network matrix remains in the zone of satisfactory performance, for different traffic amplitudes. In the new example, the network has been loaded with any-to-any traffic and the value of γ (with the precision of two decimal places) is found, by the computer simulation, for which the ring traffic latency remains below 10 time slots. The results are shown in Fig. 5. One can see that up to the network load corresponding to $a = 0.10$, the latency performance for $\gamma \leq 0.99$ is acceptable. For higher traffic values, the eligible γ decreases, and finally, reaches 0.63 for $a = 0.18$.

Fig. 6 shows how the design cost and wavelength and receiver number evolve in the same experiment. With the increase of traffic, the overall design cost, the number of wavelengths and receivers increase, meaning that the same level of performance in a ring with higher load needs to be paid with a more expensive configuration.

VI. CONCLUSION

In this paper the tradeoff between the ring design cost and the level of QoS performance in a network configured with packet aware design has been identified and quantified. Packet aware design is chosen for its stability guarantees. First, the PAD design has been introduced, and then a set of computer simulations have been performed, with a ns-2 based simulator, in order to evaluate the ring performances. On an example, it is

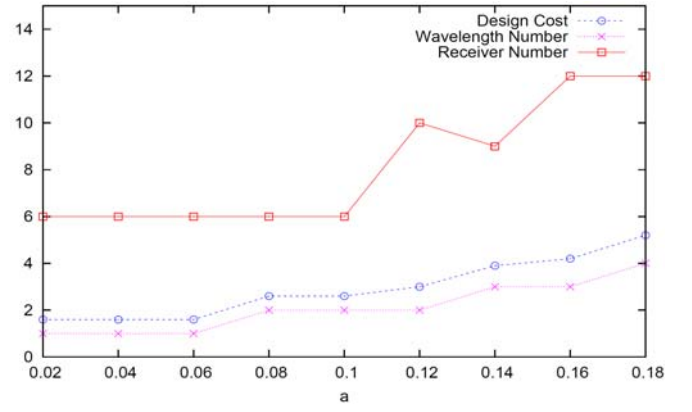


Figure 6. Design cost, wavelength and receiver number in function of the traffic amplitude a

shown that the wavelength utilization factor significantly impacts the cost of the network configuration.

The simulation results show that for the same traffic matrix, the higher network cost, but significantly better ring performances are achieved for the smaller values of wavelength utilization factor. In a 6-node ring, the satisfactory latency performance is achieved if the wavelength utilization is less than 63%. This is because, the packet aware design, although offering stability, does not guarantee the QoS performances. In future works, the ring dimensioning method containing the traffic performance guarantees should be found.

ACKNOWLEDGMENT

The authors would like to thank the Serbian Ministry of Education and Science project TR 32037 and III 44003.

REFERENCES

- [1] D. Chiaroni, A.-I. B. Labs, and R. D. Villejust, "Optical packet add / drop multiplexers for packet ring networks," *Metro*, vol. 4, no. September, pp. 103–106, 2008.
- [2] I. White, M.S. Rogge, K. Shrikhande, and L.G. Kazovsky, "A summary of the HORNET project: a next-generation metropolitan area network," *IEEE J. on Sel. Areas in Comm.*, vol. 21, pp. 1478–1494, Nov. 2003.
- [3] A. Carena *et al.*, "RingO: an experimental WDM optical packet network for metro applications," *IEEE Journal on Selected Areas in Communications*, vol. 22, pp. 1561–1571, Oct. 2004.
- [4] D. Dey, A.C. van Bochove, A.M.J. Koonen, D.H. Geuzebroek, and M.R. Salvador, "FLAMINGO: A Packet-switched IP-over-WDM All-optical MAN," ECOC, 2001.
- [5] A. Stavdas *et al.*, "IST-DAVID: concept presentation and physical layer modeling of the metropolitan area network," *Journal of Lightwave Technology*, vol. 21, pp. 372–383, Feb. 2003.
- [6] G. Hu, C. Gauger, and S. Junghans, "Performance of mac layer and fairness protocol for the dual bus optical ring network (DBORN)," Conference on Optical Network Design and Modeling 2005, pp. 467–476, Feb. 7-9, 2005.
- [7] B. Uscumlic, A. Gravey, P. Gravey, and M. Morvan, "Impact of peerto-peer traffic on the efficiency of optical packet rings," WOBS 2008.
- [8] B. Uscumlic, A. Gravey, P. Gravey, and I. Cerutti, "Traffic grooming in WDM optical packet rings," ITC 21, 2009.
- [9] B. Uscumlic, A. Gravey, I. Cerutti, P. Gravey, M. Morvan, and P. Castoldi, "Packet-Aware Design of Slotted WDM Optical Packet Rings," TELSIS 2011, Nis, Serbia.
- [10] <http://perso.telecom-bretagne.eu/bogdanuscumlic>.