LOAs as in-line amplifiers for WDM ring networks and their effect on scalability and performance

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In this work, we analyse the effect of in-line amplifiers on network performance for a WDM multiple-access unidirectional ring. For this purpose, we have carried out simulations considering several node configurations and evaluating the impact of the features and position of the amplifiers. We have chosen Linear semiconductor Optical Amplifiers (LOAs) because of their characteristics, that match those of the application: moderate gain factor and low cost. The considered node configurations differ from each other in the number of amplifiers and their gain factor and position. BER values and maximum network size have been obtained for each configuration, showing a trade-off both in the choice of the amplifier gain and its position.

1. Introduction

Next-generation optical networks transfer routing and switching functions to the optical domain, thus requiring the introduction of optical components in the nodes to carry out these functions. For this reason, physical impairments in this kind of networks can be very limiting to performance and scalability [1, 2].

A WDM multiple-access unidirectional ring network based on optical packet switching and the assessment of the involved physical impairments were presented in previous works [3, 4]. Results showed that in-line amplifiers are required in order to compensate for the component and fibre losses at the nodes. Additionally, at 10 Gb/s operation, dispersion was found to be the most limiting factor to network scalability, which suggested a slight modification of the node design by incorporating dispersion compensation modules. In this work, we further analyse the effect of the in-line amplifiers on the network performance.

2. Node design configurations

Losses in the nodes of the network and the links between them have to be compensated for by means of optical amplifiers. Four different node design configurations (A1, A2, B1 and B2) have been considered. All the amplifiers are supposed to have a set of common features, namely 7.5-dB noise figure and 17-dBm output saturated power, which are those of commercially available ones [5]. The total optical power into the demultiplexer at the add stage of the node is 5 dBm, which leads to -4 dBm per channel for the 8-wavelength WDM scheme considered. The schemes for the configurations are depicted in Figure 1 and they are briefly described in the following.

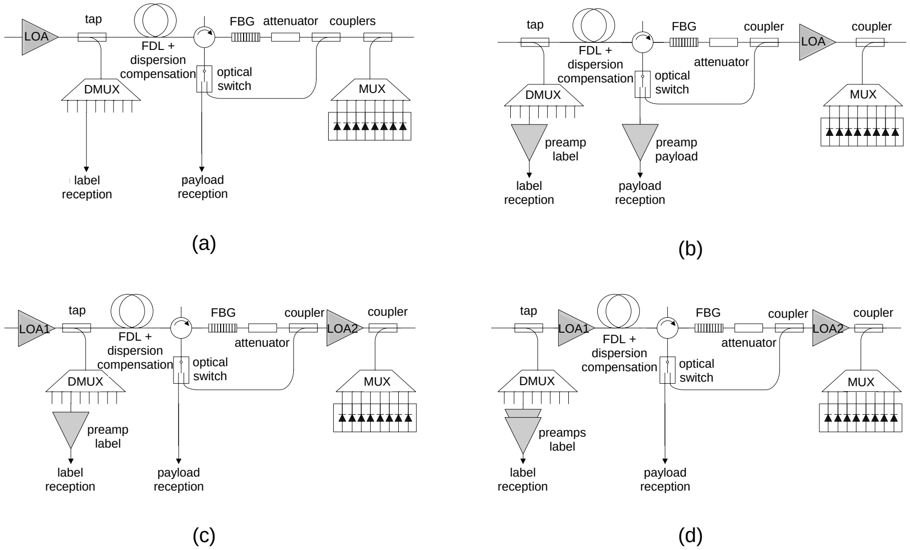


Figure 1: Node configurations considered. Configurations A1 (a) and A2 (b) include one in-line amplifier per node, while configurations B1 (c) and B2 (d) include two in-line amplifiers per node. One or more preamplifiers are placed before detection in order to meet the sensitivity requirements.

Configurations A1 and A2 include one in-line amplifier per node with its gain factor equal to the hop losses. The difference between both is the position of this in-line amplifier, which is located at the input of the node in the first case and at the output in the latter. In the case of configuration A1, the received optical power is of about -14 dBm for the label field (at the Packet Manager) and -6 dBm for the payload field (at the router input). In the case of configuration A2, the received optical power for label and payload are -31 dBm and -23 dBm respectively, requiring the introduction of preamplifiers for both fields. On the other hand, configurations B1 and B2 contain two in-line amplifiers with gain factors half the total hop losses. Position of the amplifiers is shown in Figure 1. In the case of configuration B1 one preamplifier previous to the label detection is needed (label received optical power of -22 dBm), while configuration B2 requires two preamplifiers (label received optical power of -31 dBm).

node configuration	preamps label	preamps payload	amps / node	G (dB)
A1	–	–	1	16.8
A2	1	1	3	16.8
B1	1	–	3	8.4
B2	2	–	4	8.4

Table 1: Total number of amplifiers and gain factor for each configuration.

A summary of the total number of amplifiers per node (including in-line amplifiers and preamplifiers, which are assumed to have the same characteristics) and the gain factor considered in each configuration is shown in Table 1.

3. Simulation results

We have used OptSim 4.0 from RSoft Inc. to simulate the effect of the different node configurations in the proposed network. This simulation environment allows the consideration of a vast range of optical impairments due to passive and active optical devices and includes models for most of the commercial components. In particular, LOAs were modelled by means of gain saturating optical amplifiers with the desired features. For the rest of node components, we calculated maximum loss (including connectors and polarization dependent loss, PDL) from specification sheets data and then modelled them with attenuation blocks. On the other hand, fibre was modelled by the software full fibre model, i.e. taking into account attenuation, non linear effects and dispersion, which can be a limiting factor when dealing with high bit rates (≥ 10 Gb/s) [4].

In the simulations we considered a 10 Gb/s WDM ring network with 8-wavelength scheme. The laser array launched 5-dBm total optical power (-4 dBm per wavelength) and the detection was performed by a PIN photodiode with -17-dBm sensitivity and 80-GHz prefiltering. To assess the network performance and find its scalability limits the chosen transmission quality criteria for label and payload are 10^{-12} and 10^{-9} BER respectively.

3.1 BER curves and network scalability

BER curves for increasing number of hops (i.e. increasing network size) have been obtained as a function of the received optical power for the four configurations and both label and payload. As an example, the payload curves for configurations A2 and B1 are reported in Figure 2.

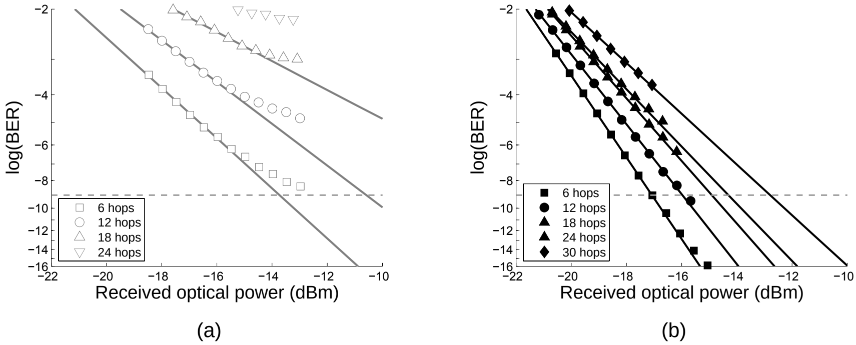
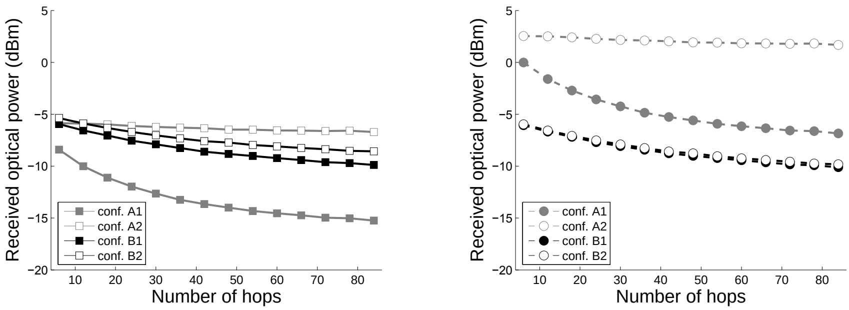


Figure 2: Payload BER vs. received optical power curves for two of the four considered node designs: (a) configuration A2 and (b) configuration B1.

Obtained BER values show that configuration B1 results in the best transmission quality for both label and payload. On the other hand, configuration A2 presents the worst performance with very high power penalty when increasing the network size.

This higher penalty is due to the degradation associated to the ASE accumulation because of the low input power to the LOA in this configuration. Figure 3 shows the received optical power dependence with the number of hops for the considered configurations and for the label (a) and payload fields (b). Configuration A1 exhibits a greater power loss when traversing nodes than the other ones. The reason for this extra loss is gain saturation in the amplifier, which arises because of the relative high input power in this case. On the contrary, configuration A2 presents the higher received power levels for both label and payload, but surprisingly this is not associated with better BER values because of the previously mentioned detrimental effect of ASE accumulation.



(a) (b)

Figure 3: Received optical power for (a) label and (b) payload as a function of the number of hops.

Network scalability was assessed by plotting the obtained BER as a function of the number of hops. Figure 4 shows eight curves representing label and payload behaviour for the four configurations together with the minimum BER quality levels imposed to each information field.

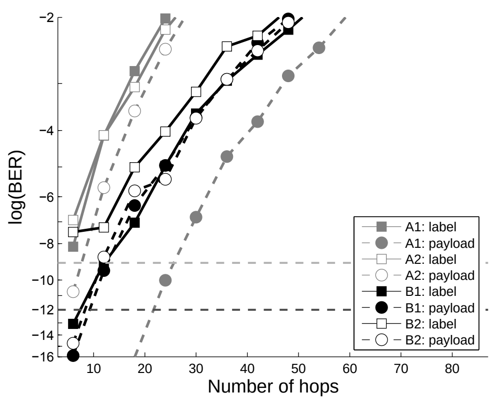


Figure 4: Scalability limits for the considered configurations.
Total launched optical power = 5 dBm (-4 dBm per channel).

There are a number of observations worth to point out from this Figure. Firstly, label transmission performs worse than payload transmission for configurations A1, A2 and B2. In fact, for these configurations, label transmission performance is unable to meet the quality requirement even for small network sizes. Only for configuration B1, where label and payload performance are similar, the quality requirement is fulfilled for a 7-node network. This issue can be overcome by increasing the received optical power by, for example, introducing additional preamplifiers at the receiver end. Therefore, this figure shows that label transmission is more limiting to network scalability than payload transmission performance because of the restrictive quality criteria considered.

3.2 Modifications of node design

In order to amend the observed limitations, some modifications to the node design configurations were introduced. Next, the separate effects of these modifications over the network performance in terms of scalability are presented.

Introduction of additional preamplifiers

We considered the increase of the received optical power by means of introducing additional amplifiers, namely two additional preamplifiers per node (for the label and the payload, respectively). Figure 5 shows the scalability limits in this case.

As can be seen, performance improves for both fields and in this case the network limits for each configuration are 26, 6, 20 and 9 nodes respectively. It is interesting to see how configurations A2 and B2 hardly benefit from this modification because in both cases the signal at the receiver end is degraded by ASE noise, which cannot be reduced by more amplification at this point. On the other hand configuration A1 greatly improves because of the low received power level for the label in the original configuration (see Figure 4).

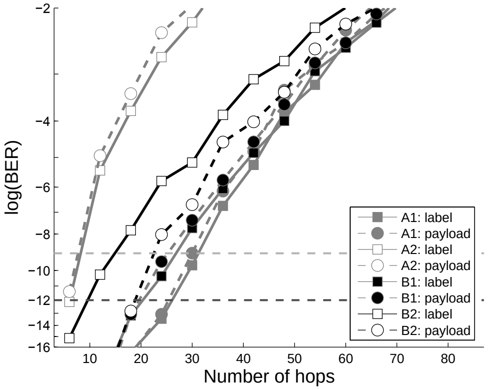


Figure 5: Scalability limits for the modified configurations after introduction of additional preamplifiers for label and payload.

The introduction of additional preamplifiers leads to a total number of amplifiers per node of 3, 5, 5 and 6 for configurations A1, A2, B1 and B2 respectively. Again configuration A1 is the best choice if this modification is considered, since it is the only one for which the number of nodes is kept within reasonable margins.

Moreover, comparison of data for this configuration in Figures 4 and 5 shows that the considered modification does not involve a significant improvement of payload performance and thus payload preamplifier can be removed. Therefore, we can conclude at this point that configuration A1 with 2 amplifiers per node presents the best behaviour in terms of scalability (21 nodes, limited by payload).

Change of the tap coupling ratio

Results presented up to now show, for most of the node designs, imbalance between label and payload performance, which contrasts with the quality criteria for both fields. The main reason for this imbalance is the use of a 90/10 tap at the input of the node to extract a small portion of the optical power to be processed by the Packet Manager. Next, we modified the node design by replacing the 90/10 tap by a 50/50 coupler, which is expected to balance the received optical power for label and payload.

The change of the coupling ratio is associated with higher losses per hop and thus requires increasing the amplifier gain factors. On the other hand, it involves an increase in the label received power, which in turn reduces the number of preamplifiers for this field. A summary of the total number of amplifiers per node (including in-line amplifiers and preamplifiers) and the gain factor considered in each configuration is shown in Table 2.

node configuration	preamps label	preamps payload	amps / node	G (dB)
A1	–	–	1	19.4
A2	1	1	3	19.4
B1	–	–	2	9.7
B2	1	–	3	9.7

Table 2: Total number of amplifiers and gain factor for each configuration when replacing the 90/10 input taps by 50/50 couplers.

When changing the coupling ratio configurations A1 and A2 require gain factors quite large and hardly commercially available. Therefore, we further analyse the remaining configurations, i.e. those containing two LOAs per node. Moreover, in order to overcome the power reduction due to saturation-induced non-compensation of the node losses, we considered four gain factor values in addition to the nominal values of Table 2.

Figure 6 shows BER as a function of the network size for label and payload in configurations B1 and B2 with 50/50 couplers. Transmission performance is clearly more balanced than when using 90/10 taps (see Figures 4 and 5), so that scalability improves. Additionally, scalability limits greatly increase when increasing the gain factor, obtaining network sizes ranging from 6 to 84 nodes when increasing LOA gain factors by 1 dB. It is important to note that increasing the amplifiers gain factor involves overcompensating hop losses except for the 0.1-dB increase. However, received optical power stabilizes when the number of hops increases and power variations not higher than 4 dB were found.

BER curves show very similar behaviour for both configurations. Nevertheless it is important to note that B1 requires one amplifier per node less than B2.

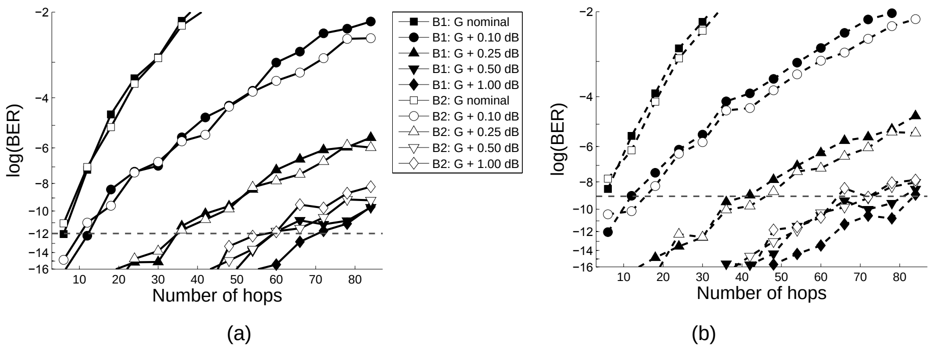


Figure 6: Scalability limits for (a) label and (b) payload for configurations B1 and B2 with 50/50 couplers. Different gain factors have been evaluated ranging form nominal G to G + 1 dB.

Finally, Table 3 summarises the limits on network scalability for the set of gain factors considered and configurations B1 and B2. Results obtained from a similar analysis in configuration A1 with two amplifiers per node are also included for comparison purposes. Limits imposed by label and payload transmission performance are obtained and gathered separately.

node configuration	field	$G_{nominal}$	$G_{+0.10\ dB}$	$G_{+0.25\ dB}$	$G_{+0.50\ dB}$	$G_{+1.00\ dB}$
A1 (90/10)	label	26	28	33	45	63
	payload	21	28	38	55	69
B1 (90/10)	label	7	21	54	59	78
	payload	12	27	58	79	> 84
B1 (50/50)	label	6	12	34	59	70
	payload	–	12	41	81	83
B2 (90/10)	label	–	–	48	73	> 84
	payload	11	30	65	> 84	> 84
B2 (50/50)	label	–	10	35	57	59
	payload	–	15	46	64	72

Table 3: Maximum network size (number of hops) for configurations A1, B1 and B2 and different amplifier gain values. Limits for node designs using 90/10 taps and 50/50 couplers are collected for comparison purposes. Note that the set of gains in these cases is different.

Despite the attempt of balancing limits set by label and payload, label transmission is still the most restrictive factor to scalability for most configurations. According to the table, designs using 90/10 taps lead to better performance than those with 50/50 couplers for configurations B1 and B2. However, the number of amplifiers per node should also be taken into account and the use of 50/50 couplers allows the removal of one preamplifier for both B1 and B2. On the other hand, configuration A1, which represented the best choice if a label preamplifier is introduced, performs worse than any of the other configurations.

4. Discussion and conclusion

In this paper we have studied the influence of the position and gain of LOAs as in-line amplifiers in WDM ring networks. A set of node configurations was defined and simulations were run in order to assess the transmission performance and obtain the limits to network scalability for each of them.

Obtained BER values showed a trade-off in the position of the amplifiers. Configurations with low input power to the amplifiers experimented quality degradation with the number of hops because of accumulation of ASE noise. On the other hand, configurations with high input power to the amplifiers showed fast received optical power loss due to the fact that the hop losses were not totally compensated because of amplifier saturation.

Several design upgrades were introduced and their effect analysed. The overall purpose of the considered modifications was the increase of the received optical power. Increase of the number of preamplifiers per node improved the transmission performance but involves higher cost per node. On the other hand, change of the coupling ratio at the node input reduced the number of amplifiers per node and thus the cost at the expense of slightly reducing network scalability.

Results showed that the best configuration in terms of viability, scalability and cost is configuration B1 requiring two 11.7-dB gain LOAs for networks with up to 70 nodes.

Acknowledgements

This work was supported in part by the funding of the Diputación General de Aragón for i3A laboratories at Walqa Technology Park and by Cátedra Telefónica.

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