Limitations Imposed by Concatenation of Optical Nodes in Optical Label Switching Networks with High Spectral Efficiency

Sérgio A. S. R. L e Paiva, Adolfo V. T. Cartaxo and Daniel D. T. Fonseca
Instituto Superior Técnico
Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
Email: nutz91@hotmail.com

Abstract — The limitations imposed by concatenation of optical nodes in 40 Gb/s/channel optical label switching networks with high spectral efficiency are studied. The maximum reachable network core nodes number, is assessed for a certain quality level. Firstly, an adaptive optoelectronic filter for improved optical single sideband signals generation from double sideband signals is described. The sideband suppression of the optical single sideband signal is quantified using sideband suppression ratio. The transmission system performance is then assessed by calculating the optical signal-to-noise ratio required for a certain bit error ratio considering both single and multi-channel transmission systems, in back-to-back configuration. The optimization of the detuning of the optical filter for the payload signal, the label-to-payload power ratio and the frequency spacing between the payload and the label signals is then performed. The impact of changing the channel spacing is also assessed. The detuning of the optical filter for the payload signal is optimized in the presence of linear transmission, considering two different optical filter bandwidths. It is shown that an optical label switching network with 40 GHz of frequency spacing between payload and label, -2.5 dB of label-to-payload power ratio and 100 GHz of channel spacing allows the payload signal to be transmitted across twelve optical network core nodes.

Index Terms — Optical label switching networks, network core nodes, optical single sideband signal, optical signal-to-noise ratio, crosstalk, linear transmission.

I. INTRODUCTION

The increasing of Internet traffic in the last years demands that the next-generation optical network support packet routing and forwarding operations at terabits per second wire rates. These networks eliminate the need of expensive optical-to-electrical conversion that is used nowadays [1], [2]. All-optical label switching (AOLS) is a potential technique that is introduced to fully use the bandwidth capacity in optical networks and in packet operations mostly carried out in the optical layer [1]. The key issue in the AOLS approach is the method of coding the optical label onto the packet. It directly determines the structure and the performance of the optical core router, as well as the channel-bandwidth efficiency and the transmission quality of the packet and its label [1], [2]. Using carrier-unsuppressed modulations combined with optical single sideband (OSSB), the group velocity dispersion (GVD) tolerance can be enhanced by means of electrical dispersion compensation. To allow the implementation of carrier-unsuppressed modulations with OSSB, the adaptive optoelectronic OSSB filter [3] can be used and a simple optical coupler can be used to multiplex the OSSB payload with the label. Experimental implementation of the label insertion/extraction modules has been demonstrated in [4]. However, the evaluation of the performance of such optical labeled signals in AOLS networks, involving transmission along fibre and pass-through different core routers (where it is required to remove the label and insert a new one), is still required to assess the benefits of such technique.

In this work, we propose the design of an optical label switching network with dispersion compensation using DCF that allows the payload signal to be transmitted across a large number of optical network core nodes.

II. GENERATION OF OSSB SIGNALS

In this section, the OSSB signal generation using the adaptive optoelectronic filter is characterized. This filter is based on imposing a phase modulation on an intensity modulated carrier-unsuppressed optical signal \(a(t)\), where \(t\) represents the time. At the input of the filter, \(a(t)\) is split into two portions by an optical splitter. One of the splitter outputs is converted to the electrical domain by a PIN and electrically processed by an electrical amplifier and a Hilbert transformer with transfer function \(H(f)\), where \(f\) is the frequency [3].
Fig. 1. Scheme of the adaptive optoelectronic OSSB filter.

Ideally, \( H(f) \) is given by \(-j \cdot \text{sgn}(f)\) where sgn(\(f\)) is the signum function. In this work, as this transfer function unfeasible by real devices we approximated it using hybrid coupler. The scheme of the proposed filter is depicted in Fig. 1.

The optical delay line compensates for the time delay introduced by the electrical components of the electrical branch of the filter.

Fig. 2. Power spectrum of an ODSB signal.

For simplification, the optical and electrical signals at the inputs of the phase modulator (PM) are considered synchronized. In Fig. 2 the spectrum of the ODSB signal, \( a(t) \), is depicted.

To obtain \( v(t) \), the electrical signal that drives the PM, the signal at the output of the PIN, \( i(t) \), passes through an electrical amplifier with a normalizing gain constant used to optimize the amplitude of the electrical pulses in order to maximize the sideband power suppression and a Hilbert transformer as indicated above in this section [5].

Fig. 3. OSSB vs ODSB in terms of SSR.

The performance criterion is the SSR which is the power difference between the spectral components spaced 20 GHz from the carrier. In Fig. 3 the power spectra of a 40 Gb/s optical double side band signal (ODSB) and a 40 Gb/s OSSB signal are shown and the SSR is indicated. The OSSB signal is a non-return to zero signal (NRZ) with a mean power of 3 dBm and extinction ratio of 13 dB. For this situation the SSR is approximately 9.1 dB.

III. ANALYSES OF THE OPTICAL NETWORK PERFORMANCE

The performance of the optical network is assessed by calculating the optical signal-to-noise ratio (OSNR) required for a bit error ratio (BER) of \(10^{-12}\), considering both single and multi-channel transmission systems, in back-to-back configuration.

At this point, it is important to introduce the structure of the optical network core node considered in this network. In Fig. 4, the simplified structure of the node is depicted.

Fig. 4. Simplified structure of the AOLS network node.
This structure is the result of a simplification process started with a more complex structure for the node. In the initial structure a wavelength converter was also considered. We decided not to include it because it increases the cost and the complexity of the system and may change the payload-label frequency spacing when the packet (payload and label) is being transmitted across the network. The experimental payload optical filter has a -3 dB bandwidth of 37.57 GHz and -15 GHz of detuning relative to the carrier frequency and the experimental label optical filter has a -3 dB bandwidth of 18.75 GHz. The new label generator, generates a 2.5 Gb/s ODSB label signal.

The study of the performance of this system is based on the optimization of the payload-label frequency spacing and the label-to-payload power ratio (LP) in terms of minimization of the optical signal-to-noise ratio (OSNR) required for a BER of $10^{-12}$.

III. A. RESULTS FOR 100 GHz OF CHANNEL SPACING

In this section we present the principal results obtained for a channel spacing of 100 GHz and considering back-to-back configuration and a 40 Gb/s OSSB payload signal.

Fig. 5 and Fig. 6 show the OSNR required for a BER of $10^{-12}$ as a function of the payload-label frequency spacing, for a multi-channel system (with three channels spaced of 100 GHz from each other) and considering three different values for LP ratio, for the payload and label signals respectively.

Fig. 5 shows two different behaviors depending on the payload-label frequency spacing. For payload-label frequency spacings lower than 35 GHz, the OSNR required for a BER of $10^{-12}$ gradually decreases. This is the consequence of reducing the interference between label and payload. For frequency spacings between label and payload higher than 35 GHz, the effect of inter-channel interference degrades the performance. That is the reason why the required OSNR increases. Analyzing the LP influence on the required OSNR, Fig. 5 shows that when the LP decreases the OSNR also decreases, as it means a reduction in the label power and, consequently in the strength of the label-payload interference.

Fig. 6 shows that the OSNR required for a BER of $10^{-12}$ is almost the same considering any of the LP values and a payload-label frequency spacing of 35 GHz. By considering both Fig. 5 and Fig. 6 we conclude that the optimum value for LP is -2.5 dB and the optimum value for payload-label frequency spacing is 35 GHz.

III. B. RESULTS FOR 50 GHz OF CHANNEL SPACING

Meanwhile it was also studied if considering 50 GHz of channel spacing is viable or on the contrary, if it only increases the interference and affects negatively the system performance.
This analysis is made considering values of payload-label frequency spacing between 10 and 20 GHz. Since this frequency spacing between signals has to be reduced as a consequence of the channel spacing reduction, the power of the label cannot be so high as in the case of 100 GHz of channel spacing because it increases the label-payload interference. That is why we consider lower values for the LP ratio.

Fig. 7 depicts the required OSNR for the payload signal with the increase of payload-label frequency spacing for values of LP of -10 dB and -7.5 dB.

The reason why we only considered payload-label frequency spacing between 15 and 20 GHz, for the payload signal is explained by the high label-payload interference for frequency spacing lower than 15 GHz and the high channel interference for frequency spacing higher than 20 GHz.

Fig. 8 shows the required OSNR for the label signal with the increase of payload-label frequency spacing for values of LP of -10 dB and -7.5 dB.

Considering both Fig. 7 and Fig. 8, we can conclude that the optimum values for the LP ratio and the payload-label frequency spacing is -7.5 dB and 15 GHz, which assure a minimum value for the OSNR required for a BER of 10^{-12}.

IV. LINEAR TRANSMISSION MULTI-SECTION SYSTEMS

In this section, we will study the effects of linear transmission on the payload signal considering a multi-channel multi-section system. The channel spacing considered is 100 GHz.

The performance is evaluated in order to assess the maximum number of optical network core nodes that the transmitted signal can cross before its BER is not acceptable. Also, the influence of the LP ratio is taken in count.

Fig. 9. Q factor of the payload signal as a function of the number of sections crossed by the transmitted signal, considering a -3 dB bandwidth for the payload optical filter of 37.57 GHz and LP = -2.5 dB.

Fig. 9 depicts the quality of the transmitted payload signal, measured by the Q factor as a function of the number of sections of the optical transmission system. If we consider a -3 dB bandwidth for the payload optical filter of 37.57 GHz and the optimum value of LP determined earlier in this section for multi-channel transmission with channel spacing of 100 GHz, the transmitted signal can cross 7 sections (nodes). This is shown in Fig. 9.
Considering the influence of the LP ratio value variation in system performance, we can see in Fig. 10 that when the value of LP decreases the Q factor increases, as expected.

Comparing the curve for the LP = -2.5 dB in Fig. 10 with the one depicted in Fig. 9 we can see the influence of using a filter with a large bandwidth in the performance of the system. Considering a -3 dB bandwidth of 62.62 GHz for the payload optical filter, the number of sections which the transmitted signal can cross increases. In this situation the payload signal crosses at least 12 sections, before it’s too degraded.

V. CONCLUSION

Limitations imposed by the concatenation of optical nodes in optical label switching networks with high spectral efficiency were studied numerically.

We demonstrated that an optical label switching network with 40 GHz of frequency spacing between payload and label, -2.5 dB of label-to-payload power ratio and 100 GHz of channel spacing allows the payload signal to be transmitted across twelve optical network core nodes with a BER not exceeding $10^{-12}$.

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