Influence of laser wavelength detuning and optical filtering on the performance of FSK/IM transmission schemes

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In this paper, the impact of laser frequency detuning and optical filtering in a combined FSK/IM modulation format in a 3 channel WDM system is investigated by simulations. We consider a complete routing node, which consists of (de)multiplexers, a wavelength converter and a passive wavelength router. The performance of the system is assessed by determining the Q-factor and the eye opening penalty.

Introduction

Due to the increasing bandwidth provided by optical fibres, a gap between high line rates and the limited processing speed of electronic IP routers has arisen.

A technique attempting to close this gap in IP routing over wavelength division multiplexing (WDM) optical networks is all optical label switching (OLS) [1]. Here aggregated IP packets are composed and accompanied by an optical label, which is used by the core network nodes for routing and forwarding decisions. In each core node, the payload remains in the optical domain, while the label is recovered, processed, updated and reinserted with the payload. A method for labelling IP packets is orthogonal FSK/IM modulation scheme, where the payload data is intensity modulated (IM) and the label information is frequency modulated (FSK) [2]. Frequency-shift keying (FSK) data signals can be created by modulating the phase section of Grating Assisted Coupler Sampled Reflector (GCSR) lasers [3].

Transmission through optical filters, e.g. WDM (de)multiplexers, arrayed waveguide gratings (AWG), may cause signal degradations, limiting the reach of OLS transparent optical networks [4, 5]. As the FSK modulation of the combined FSK/IM modulation scheme results in a broadening of the optical spectrum, this makes the alignment laser-filters a critical design issue. If the IM/FSK signal is not well filtered, the orthogonal independence of the modulation formats is ruined. The two FSK tones will no longer have equal amplitude, therefore inducing intensity fluctuations and influencing the IM payload by FSK to IM conversion.

In this paper we present a simulation of the performance of the combined FSK/IM scheme with respect to signal degradation due to laser nominal wavelength detuning and optical filtering in a 3 channel WDM system.

Combined FSK/IM modulation transmission scheme and routing.

A generic core router, the system under study, forwards and routes the labelled IP packets according to a routing table. As shown in Figure 1, the node is composed of a demultiplexer (demux), wavelength converters (λc) and an AWGR. After demultiplexing the optical WDM signal the FSK label is read, while the payload data is kept in the optical domain. According to the routing table, the payload is converted to the desired wavelength and at the same time the new label is inserted. The passive Arrayed Waveguide Grating

Router (AWGR) directs the packet to the appreciated output port. When crossing one node, the packet passes the demux, the λc and the AWGR components.
For efficient simulation the core node is limited to three channels. In contrast to a real node, the FSK label is not read and processed by a routing table. We generate a pseudo random bit sequence FSK encoded and insert it on the IM payload at a chosen wavelength. The wavelength converter is a Mach-Zehnder Interferometer (MZI) equipped with Semiconductor Optical Amplifiers (SOA) [2,6]. During the wavelength conversion the label is erased, as only the IM modulated payload is transferred from the old wavelength to the new one, in which the new FSK signal has been pre-modulated.

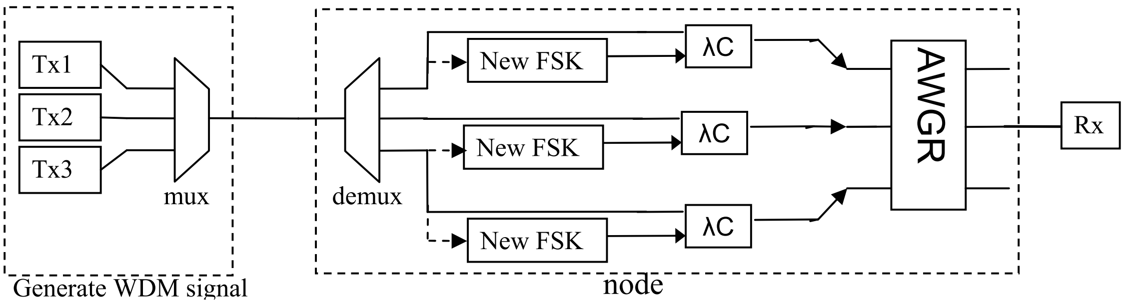

Figure 1 simulation architecture of core node under study (λc : wavewlength converter)

Simulation results

For the simulations, all performed in VPI TransmissionMaker of VPI systems, the following system parameters are used.
The transmitter is build from a continuous wave (CW) laser source, a chirp-free IM modulator with an extinction ratio of 7dB, a FSK modulator, both loss-less. The bitrate of the IM payload is 10 Gbit/s and the FSK label bitrate is 156.25 Mbit/s, a subrate of the IM bitrate. The data format is 2^{23}-1 pseudo random nonreturn-to-zero (NRZ) for the payload and 2^{7}-1 pseudo random NRZ for the label, which has a frequency deviation of 20 GHz.
The (de)multiplexer and the AWGR have a first order Gaussian filter response with a full-width half maximum (FWHM) bandwidth of 85GHz.
The receiver is modelled as a PIN photodiode followed by an electrical Bessel third order low pass filter with a 3 dB cut-off frequency equal to 0.7 times the bit rate.
Initially, all centre frequencies of the components are set to the three channel frequencies of 192.0THz, 192.2THz and 192.4THz.
In the simulations the laser emission frequency of transmitter 'Tx2' is swept from 192.17 to 192.2 THz. The receiver block "Rx" only examined the IM signal. Note that the payload is generated in a distant node and is kept in the optical domain and therefore more prone to degredation due to filtering. The FSK label is regenerated in each node and consequently suffers less from the frequency misalignments.
To assess the influences of each of the node components, several simulations setup were performed.

A. The receiver "Rx" is placed directly after the demultiplexer 'demux'.
B. To determine the influence of the AWGR, we placed the receiver after the AWGR and disabled the wavelength converters. This indicates the packets only pass the demux and AWGR.

C. Only the demux and λc are investigated
D. The whole node setup (demux+λc+AWGR) is taken into account.

The performance of the received IM payload signal is evaluated in two ways. The first method is determining the Q-factor, which is defined as $Q=(\mu_1-\mu_0)/(\sigma_1+\sigma_0)$, where μ is the arithmetic mean of sample points of "one" resp. "zero" bits while σ is the standard deviation of the points. Hereby the transmitted bitstream is used to determine if the received bit is a "one" or "zero" and not whether it is above or below a certain threshold. The results are plotted in Figure 2. Curve 'D', the whole node, shows a Q-factor of 8 for no laser frequency detuning. The Q-factor drops below 2, when the detuning is more than 10GHz. When taken a Q-factor of 6 as a reference, a laser frequency detuning of 3 GHz is tolerable.

The second evaluation method uses eye opening analysis. By calculating the eye opening ratio, defined as "eye opening/eye height", we have an indication of the eye opening with respect to the received total power. The results are shown in Figure 3, which when looking again at curve D, shows a ratio of almost 50% for no laser frequency detuning and a closed eye for a frequency detuning of 15GHz. In comparison with the Q-factor of 6, 3 GHz laser frequency detuning results in a eye opening ratio of more than 40%.

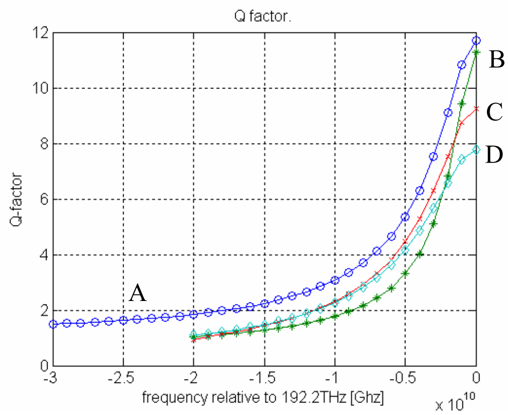

Figure 2 Q-factor

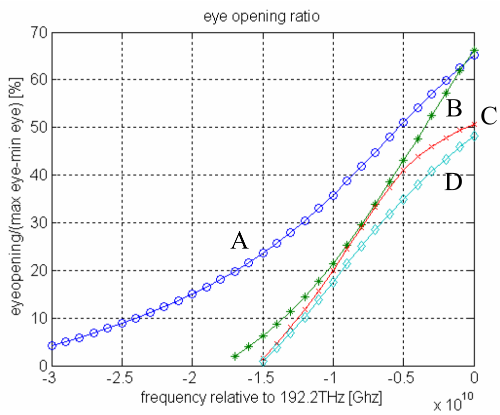

Figure 3 eye opening ratio

A: (de)mux; B:(de)mux+awgr; c:(de)mux+λc; D: (de)mux+λc+awgr

To study the effect of the optical filter shape, simulations were performed using a flat-top filter. This trapezoidal shaped filter has the same FWHM as the Gaussian filter. The architecture of Figure 1 is used for the simulations, except that the Gaussian filters in the multiplexer, demultiplexer and AWGR are replaced by the flat-top filter.

The following studies were performed.

A. Only the demultiplexer with flat-top filters
B. The whole node (demux+λc+awgr, all flat-top filters)
C. Demux with Gaussian filters. The result is a copy from Figure 2 and Figure 3 and is only meant to be a reference.

D. To investigate the influence of FSK conversion into the IM payload, the simulation was executed without any FSK modulation. Again the (de)mux and AWGR had initial Gaussian optical filters.

Figure 4 and Figure 5 show the result of "A,B,C and D". It states a major improvement of the tolerable laser frequency detuning. Even after a detuning of 30 GHz, the Q-factor is above 6.

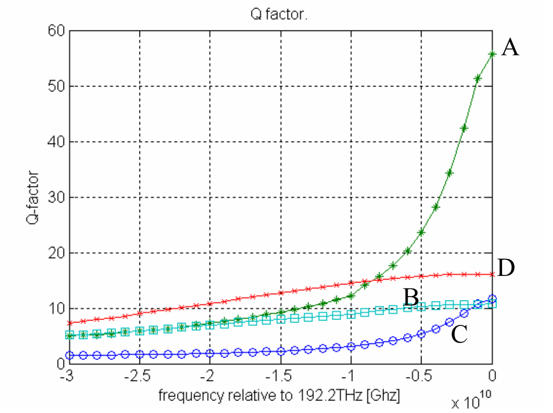

Figure 4 Q-factor (flat-top filter)

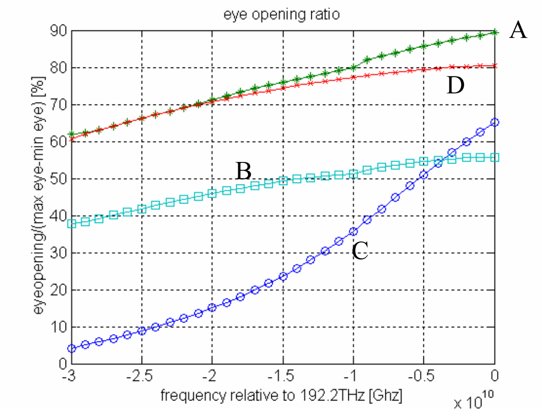

Figure 5 eye opening ratio (flat-top filter)

A: (de)mux {flat-top filter} ; B:(de)mux+λc+awgr {flat-top filter}; C :(de)mux {Gaussian filter} ; D :(de)mux just IM modulation{Gaussian filter}

Conclusions

We have presented a study on the impact of laser wavelength detuning and optical filtering in a combined FSK/IM modulation scheme**.** A 10 Gbit/s IM payload is orthogonal modulated with a 156.25 Mbit/s FSK label. The effect of WDM (de)multiplexers and AWGR is considered on the performance of the IM payload signal.

The simulations show that with a Gaussian shaped optical bandpass filter, the permitted laser frequency detuning for Q=6 is limited to just a few GHz. When using an optical filter with a more flat-top shape, instead of Gaussian, the acceptable detuning is increased substantially. This indicates that with a FSK/IM modulation format, the filter response curves of the (de)multiplexers and AWGR of the node should have a flat bandpass, to reduce the FSK to IM modulation conversion.

The future is focused on investigation the influence of channel spacing, FSK frequency deviation and cascading nodes.

Acknowledgements

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