Combined IM/FSK Format for Payload/Orthogonal Label of IP Packets in WDM Networks

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We present a detailed analysis of combined IM/FSK modulation format for payload/orthogonal labeling of IP packets in WDM networks supported by GMPLS. This scheme is superior to combined IM/DPSK regarding laser linewidth requirement and equipment simplicity. Simulation results show that a Gaussian shaped optical filter for selecting one of the two FSK tones offers better performance than a Lorentzian filter type. IM and FSK receiver sensitivity do not degrade in the wavelength range operation of ± 4 nm from the complete dispersion compensation wavelength for single channel although careful dispersion management is required.

1. Introduction

There is a gap between the bandwidth provided by the optical fibers and the bandwidth that can be handled by electronic IP routers within today's Internet. Using label swapping, IP payload can be kept in the optical domain without the need to pass IP packets through electronics whenever a routing decision is made. Directly transporting IP packets over WDM networks by avoiding the ATM (asynchronous transfer mode) and/ or SDH (synchronous digital hierarchy) layers is a more cost-efficient network solution. Therefore, IP over WDM networks supported by GMPLS (generalized multiprotocol label switching) [1] is being considered as the next generation optical Internet.

We proposed a combined optical modulation format for IP payload/label and found that the IM/FSK format provides better performance than the IM/DPSK, regarding the laser linewidth requirement and simplicity of direct detection systems [2]. In this paper, we extend the analysis in [2] to include residual intensity modulation (RIM) due to FSK modulation of laser, wavelength range operation of single channel, types and parameters of filter.

2. IM/FSK format for Labeling IP Packets in IP over WDM Networks Supported by GMPLS

The basic concept of transporting a labeled IP packet over WDM networks supported by the GMPLS using IM/FSK format is as follows. IP packets from access or metro network are managed in an edge router (see Fig. 1). After these processes, a fast tunable laser followed by an external chirp-free intensity modulator is used to carry IP payload at data rate of 10 Gb/s. A label written in FSK format (at data rate of 155 Mb/s) by direct frequency modulation of a fast tunable laser is imposed orthogonally to the intensity modulated IP payload. Then, the labeled IP packet is transported on a given wavelength and injected into the WDM core network.

The core routers (see Fig. 2) perform forwarding and routing operations by label swapping with wavelength conversion according to a routing table. To perform label swapping, a part of the signal is tapped for reading of the FSK label, while IP payload data are kept in the optical domain. According to the routing table, a new FSK label (and optionally a new wavelength) is written to the IP packet. The label swapping and wavelength conversion process is performed by an AOLSWC (all-optical label swapping wavelength converter). The IP packet is then routed to the appropriate output port through an Arrayed Waveguide Grating Router (AWGR). In this way, a complex space-switch is avoided.

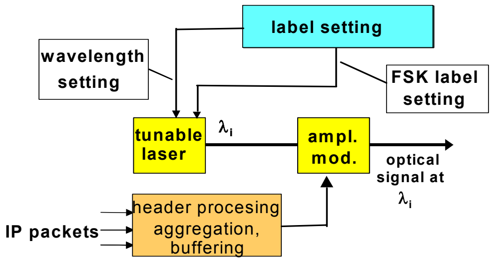


Fig. 1. Edge router

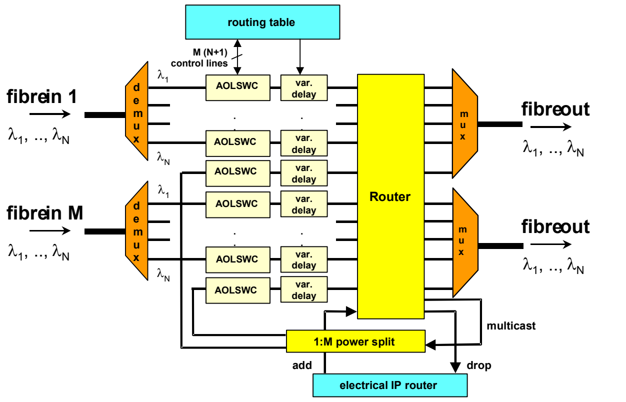


Fig. 2. Core router

The core router also provides multicasting and add-drop functions. The IP packets from multicast output of the AWGR are fed via a power splitter to a number of AOLSWCs at the input of the AWGR, thus the IP packets are multicasted to the appropriate output fibers. Add-drop multiplexing function is performed in a similar way.

The AOLSWC is composed of semiconductor optical amplifiers integrated in a Mach-Zehnder interferometer (see Fig. 3). Replacing a label is easy because the FSK label contained in the IP packets is lost during wavelength conversion. Simultaneously the IP payload intensity modulation is transferred from the incoming signal to the outgoing signal at a new wavelength in which the new FSK label has been reinserted by direct FSK modulation of a fast tunable laser. Therefore, the optical label swapping preserves the optical transparency of the IP payload that is required for all-optical packet switching.

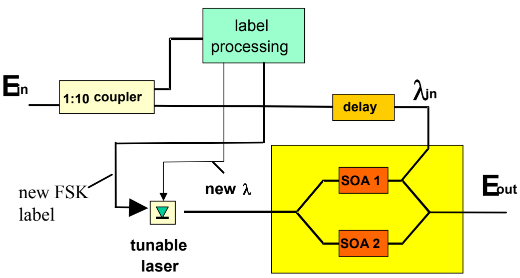


Fig. 3. All-optical label swapping wavelength converter

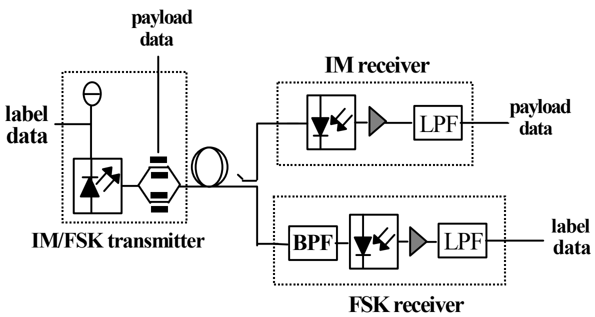


Fig. 4. Diagram of IM/FSK transmission system for simulation

3. Combined IM/FSK Modulation Format

The diagram of the IM/FSK transmission system is shown in Fig. 4. IM and FSK receiver sensitivity are defined for BER of 10^{-9} and 10^{-12} (as label detection should be extremely reliable), respectively. To obtain FSK format, a laser is biased to produce an optical frequency representing a bit '0' and a small current increment is used to shift the frequency by the frequency deviation of 20 GHz to represent a bit ‘1’. Because of the current increment, the output power of laser is also increased, thus a residual intensity modulation (RIM) is yielded. We found that IM sensitivity is influenced by the presence of RIM. At RIM of 0.97 dB, the IM sensitivity degradation is around 2.5 dB (see Fig. 5).

We found that there is no sensitivity degradation of the IM payload and of the FSK label receiver in the wavelength range operation of ± 4 nm from the complete dispersion compensation wavelength (1553.6 nm) for single channel (see Fig. 6). The reason is that the total dispersion at wavelength of 1557.6 nm (10.37 ps/nm) and at 1549.6 nm (-13.39 ps/nm) is so small that the sensitivity is hardly degraded.

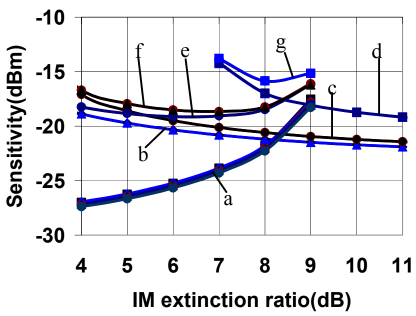


Fig. 5. Sensitivity of IM payload and FSK label receiver as a function of IM extinction ratio at FSK frequency deviation of 20 GHz and laser linewidth of 100 MHz for several values of RIM (a = FSK: 0; 0.46 and 0.97 dB, b = IM: 0 dB, c = IM: 0.46 dB, d = IM: 0.97 dB, e = overall: 0 dB, f = overall: 0.46 dB, g = overall: 0.97 dB).

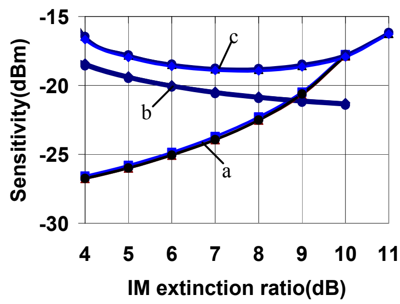
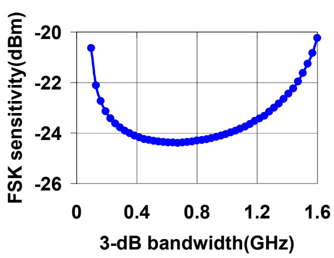


Fig. 6. Sensitivity as a function of IM extinction ratio at an FSK frequency deviation of 20 GHz, linewidth of 100 MHz and RIM of 0.46 dB (a= FSK: 1549.6, 1553.6 and 1557.6 nm, b = IM: 1549.6, 1553.6 and 1557.6 nm, c = overall: 1549.6, 1553.6 and 1557.6 nm).

Two types of optical filter (i.e. Lorenztian and Gaussian shaped filter) are applied for the bandpass optical filter (BPF in Fig. 4) in the FSK receiver. We found that for a Lorentzian filter (e.g. FP filter), the optimum 3-dB bandwidth is 672 MHz for finess (F) =313, 942 MHz for F=138, 1170 MHz for F=77, and 1644 MHz for F=49, respectively, while for a Gaussian filter, it is 13 GHz (see Fig. 7).



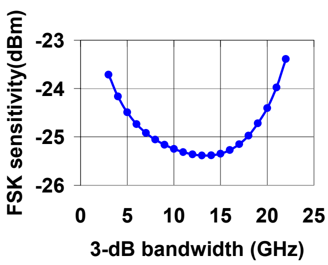


Fig. 7. FSK sensitivity as a function of 3-dB bandwidth of FP filter for F = 313 (left) and of Gaussian filter (right).

Furthermore, we analyzed the influence of shifting of the center emission frequency of laser with respect to the center frequency of the filter on the FSK receiver sensitivity. We found that an FSK sensitivity penalty of 5.0 to 6.5 dB occurs when the center emission frequency of laser is shifted ± 5 GHz for FP filter, while for Gaussian filter it is only 2 dB (see Fig. 8).

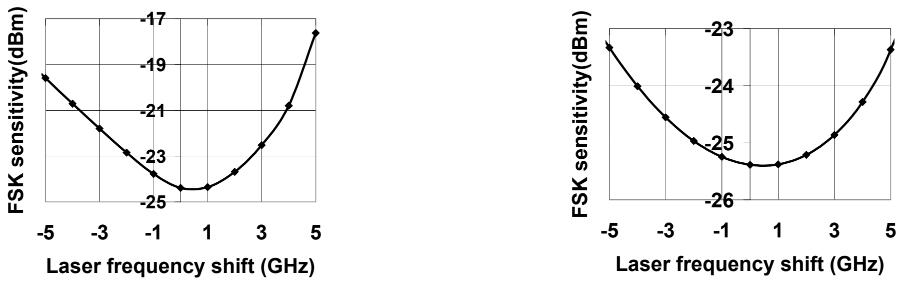


Fig. 8. FSK sensitivity as a function of laser center emission frequency shift for FP filter (left) and Gaussian filter (right).

4. Conclusions

Combined IM/FSK format for payload/orthogonal labeling of IP data in IP over WDM networks supported by GMPLS is promising for the next generation optical Internet applications.

Simulation results show that IM receiver sensitivity is influenced by the presence of residual intensity modulation. IM and FSK receiver sensitivity do not degrade in the wavelength range operation of ± 4 nm from the complete dispersion compensation wavelength for single channel, and Gaussian shaped optical filter offers better performance than a Lorentzian one.

5. Acknowledgements

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References

[1] A. Banerjee, et al., "Generalized Multiprotocol Label Switching: An Overview of Routing and Management Enhancements", IEEE Communication Magazine, Jan. 2001, pp.144-150.

[2] Ton Koonen, Sulur, Idelfonso Tafur Monroy, Jean Jennen, and Huug de Waardt, "Optical Labeling of Packets in IP-over-WDM networks", in Proc. of ECOC'02, Copenhagen, Sep.9-12, 2002, paper 5.5.2.