«Investigation of Spectrally Efficient Transmission for Differently Modulated Optical Signals in Mixed Data Rates WDM Systems»

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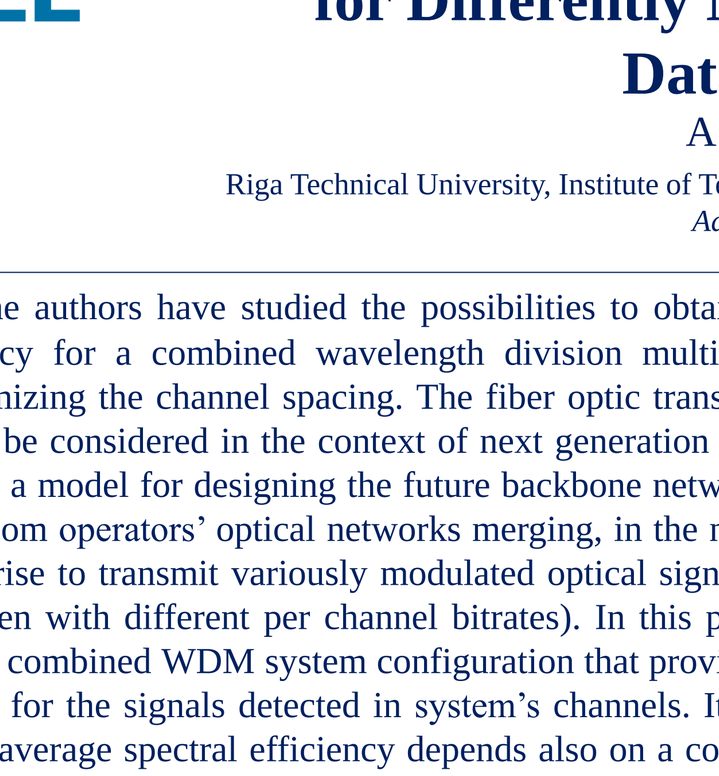
Abstract - The authors have studied the possibilities to obtain the maximum spectral efficiency for a combined wavelength division multiplexing (WDM) system by minimizing the channel spacing. The fiber optic transmission systems under study can be considered in the context of next generation optical networks and is offered as a model for designing the future backbone networks. In the case of different telecom operators' optical networks merging, in the nearest future the necessity may arise to transmit variously modulated optical signals over a single optical fiber (even with different per channel bitrates). In this paper the authors show an optimal combined WDM system configuration that provides the least bit-error-rate values for the signals detected in system's channels. It is revealed that such a system's average spectral efficiency depends also on a combined system's configuration in the case of channel separation with equal frequency intervals.



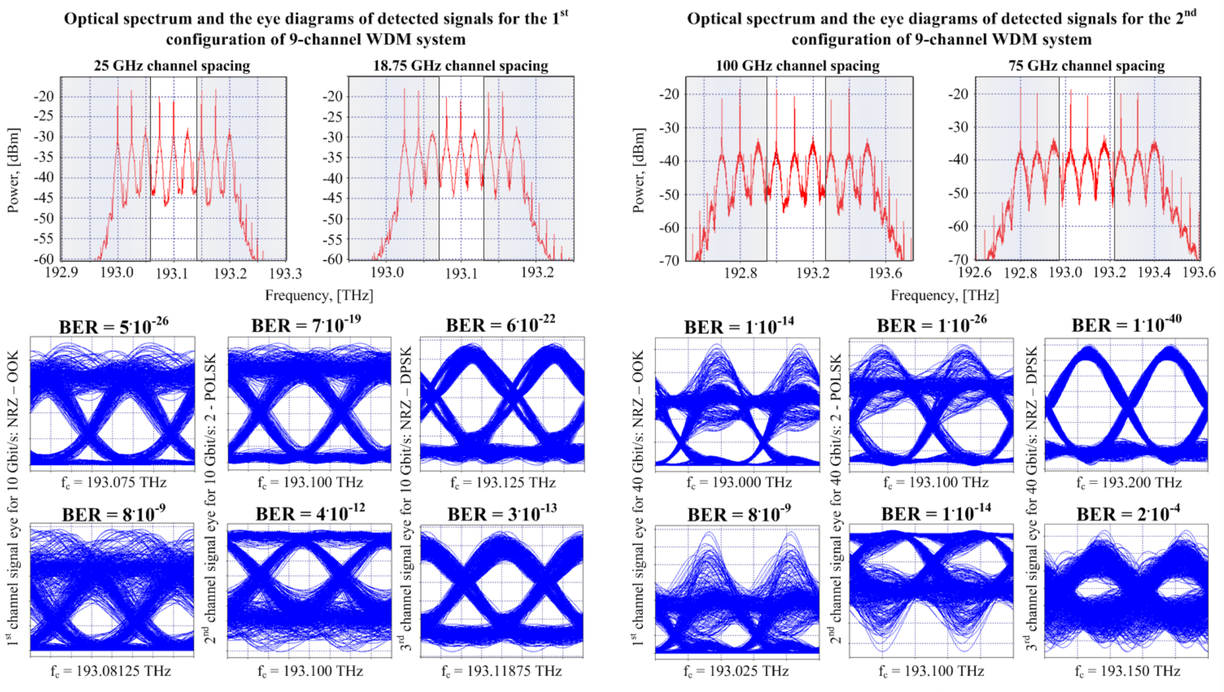
PPG – Pulse Pattern Generator
CW – Continuous Wavelength
MZM – Mach-Zehnder Modulator
POLM – Polarization Modulator
OPM – Optical Phase Modulator
EBF – Electrical Bessel Filter
OSGF – Optical Super Gaussian Filter
ES - Electrical Splitter
BDPSK Rx – Balanced DPSK Receiver
PRx – POLSK Receiver
PIN – PIN Photodiode
Q Est – Q factor Estimator
BER Est – Bit-Error-Rate Estimator
ESA – Electrical Signal Analyser

Fig. 1 Simulation scheme of a developed 9-channel combined WDM system and block diagram of the channel transmitting and receiving units for NRZ – OOK, 2 – POLSK and NRZ – DPSK optical signal modulation formats.

Optical signals' freedom degrees

1. *Intensity* → NRZ-OOK: the traditionally employed modulation format in FOTS due to its relatively simple realization, e.g. using MZM or EAM.
2. *Phase* → NRZ-DPSK: high tolerance to NOE, e.g. SPM and XPM, and the improvement of receiver sensitivity threshold.
3. *State of polarization* → 2-POLSK because of its immunity to phase noise of the laser sources and SPM.

Analysis of channel spacing (1/2)

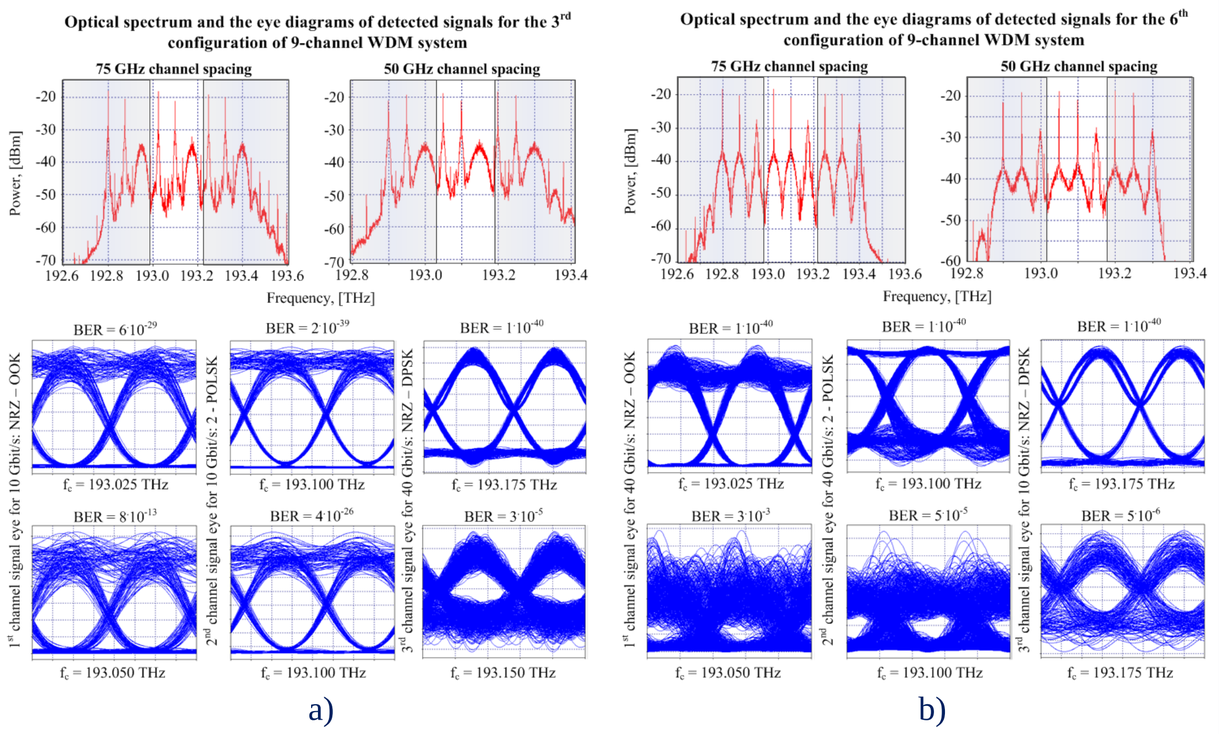


a) b)

Fig. 2 Combined system's output optical spectrum and the eye diagrams of detected signals: a) B=10 Gbit/s per channel bitrate; b) B=40 Gbit/s

Analysis of channel spacing and bit-error-rate (2/2)

[1st: NR-OOK (10 Gbit/s)]+[2nd: 2-POLSK (10 Gbit/s)]+[3rd: NRZ-DPSK (40 Gbit/s)] system's configuration (see Fig. 3a) ensures the detected signal BER values that are the highest in a system's channels as compared with the [1st: NRZ-OOK (10 Gbit/s)]+[2nd: 2-POLSK (40 Gbit/s)]+[3rd: NRZ-DPSK (10 Gbit/s)] and [1st: NRZ-OOK (40 Gbit/s)]+[2nd: 2-POLSK (10 Gbit/s)]+[3rd: NRZ-DPSK (10 Gbit/s)] configurations.



a) b)

Fig. 3 Optical spectrum and the eye diagrams of detected signals for mixed data rate combined WDM system: a) **the worst case of SE = 0.27 bit/s/Hz**; b) **the best case of SE=0.40 bit/s/Hz**.

The best configuration of a combined WDM system where optical signals are transmitted with 40 Gbit/s in two channels is the [1st: NR-OOK (40 Gbit/s)]+[2nd: 2-POLSK (40 Gbit/s)]+[3rd: NRZ-DPSK (10 Gbit/s)]. It provides the lowest average BER value for the detected signals (see Fig. 3b) as compared with the [1st: NRZ-OOK (40 Gbit/s)]+[2nd: 2-POLSK (10 Gbit/s)]+[3rd: NRZ-DPSK (40 Gbit/s)] and [1st: NRZ-OOK (10 Gbit/s)]+[2nd: 2-POLSK (40 Gbit/s)]+[3rd: NRZ-DPSK (40 Gbit/s)] configurations.

The estimation of spectral efficiency

The investigated combined WDM system channels' average spectral efficiency was calculated assuming that we operate with discrete noiseless channels and all the sent information is received unchanged at the other end (i.e. BER →0).

Conclusions

The minimum channel spacing that ensures the BER value of detected signals below the maximum threshold of 10^{-12} for 10 Gbit/s per channel bitrate and 10^{-16} for 40 Gbit/s is:

- **25 GHz** if per channel bitrate (B) in each system's channel is equal to 10 Gbit/s;
- **75 GHz** if at least in one system's channel B = 40 Gbit/s;
- **100 GHz** if optical signals are transmitted with 40 Gbit/s per channel bitrate.

Based on these data, the channel's average spectral efficiency for each combined system's configuration has been estimated. It is equal to:

- **0.27 bit/s/Hz** if only in one of the three channels of the system B = 40 Gbit/s;
- **0.40 bit/s/Hz** if in all system's channels optical signals are transmitted with equal per channel bitrate (10 or 40 Gbit/s) or at least in two of the three channels that form the central group of a system's channels B = 40 Gbit/s.

An important point is that the channels' average spectral efficiency for each combined system's configuration was obtained for equal channel spacing. Significantly higher spectral efficiency could be achieved if for the channel separation in such mixed data rate WDM systems unequal intervals were taken.

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