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SIMULATION OF A 3.2 Tbit/s SUBMARINE SYSTEM (80 × 40 Gbit/s) OVER 400 km WITH ONLY 3 SPANS

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Transmission of 80x40 Gbit/s channels has been simulated over straight-line 400 km NDSF with 100 GHz spacing and a record 90-and-120 km amplifier spacing. The amplifier and fibre modules are designed for wide-band simulation and include file-input wavelength-dependent characteristics. All the simulations were done based on a very powerful software simulator tool: PDTS – produced by Virtual Photonics.

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1. Introduction

Oceans represent some of the most challenging environments on earth, separating people and businesses around the world. Global optical internet connectivity must cross-seas and oceans, and have the ability to provide customers with seamless and reliable connections from any place, at any time. Through the launch of its Submarine Solutions, Nortel Networks continues to be on the edge of disruptive technological innovation, with the extension of a truly global Optical Internet.

The current multimedia revolution is creating tremendous growth in the undersea networking space as service providers scramble to meet the insatiable demand for global bandwidth. The need for an integrated, cost-effective, high capacity networking infrastructure has never been more critical, and Nortel Networks is well positioned to capitalize and deliver on this exciting opportunity.

Nortel Networks introduces the OPTera Long Haul 5000 Optical Line System, as part of its industry-leading portfolio of next – generation open optical systems for backbone networks.

The OPTera Long Haul 5000 is capable of:

- Transmitting 1 million simultaneous high quality digital television
- Carrying 100 million simultaneous Internet connections & 6 million simultaneous high speed Internet access connection.

In this paper, we report a significant advance in the field of long-haul submarine optical communication systems by demonstrating the feasibility of transmission 3.2 Tbit/s capacity (C band and L band) over 400 km of an existing fibre type. This straight-line system operated with a spectral efficiency of 0.4 bit/s/Hz and record span lengths of 90-and-120 km at 40 Gbit/s line rate.

2. System configuration set-up

The experimental set-up is shown in Fig. 1.

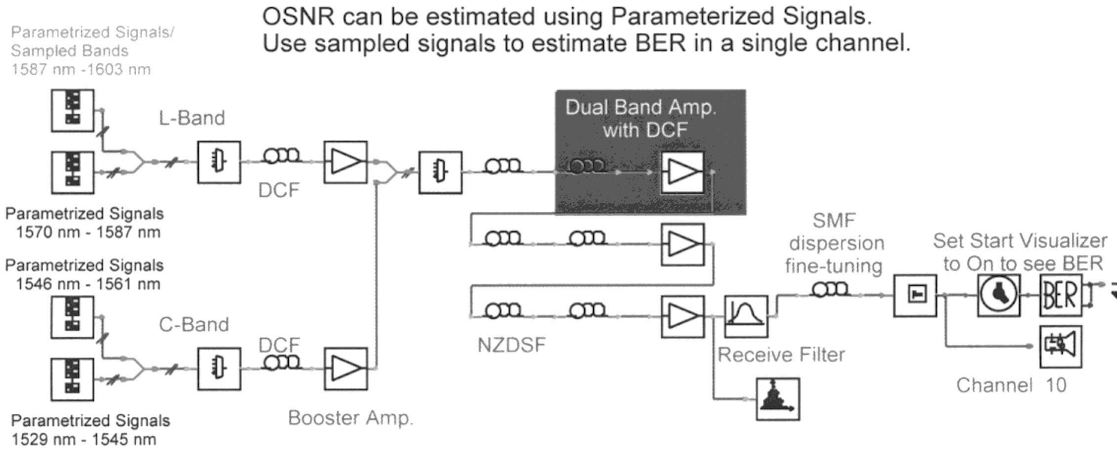

Fig. 1. 80 channel dual-band WDM system schematic.

The simulation is for an 80 – channel system over two wavelength bands. The total capacity is 3.2 Tbit/s. The bit rate per channel is 40 Gbit/s, which requires a channel spacing of 100-GHz based on the ITU-T grid requirements.

In practice, two groups of signals are used, one occupying the C band and one the L band. The dispersion in each band is pre-compensated, and the bands amplified by EDFAs – Erbium Doped Fibre Amplifier before combining.

The transmission comprises two 90-km spans and one 120-km span, with combined Raman/Erbium amplifiers after each span. The amplifiers give a gain around 26.5 dB. The span loss is 28.665 dB. The transmitted power per channel is 0 dBm.

The fibre spans use non-zero Dispersion Shifted Fibre DCF - with a dispersion of 5.7 ps/(nm.km), and a slope of 0.037 ps/(nm^2.km), but is mostly compensated by high-slope DCF within the amplifiers. In addition, there is –160 ps/nm of dispersion compensation before the power booster amplifiers, and dispersion compensation after the final amplifier tuned to the required channel.

The technical characteristics of the components used to simulate the WDM (80 channels $\times$ 40 Gbit/s) with 100- GHz channel spacing are described below.

The laser is a InGaAsP/InP MQW-DFB laser diode modules designed for fibre optic communication systems and has the following technical characteristics:

- Optical output power 1 mW
- Channel Spacing: 100 e9 Hz
- Emission Frequency of First Channel: 187 e12 Hz

On the other side of the system we find the photodiode - PIN described by the following technical characteristics:

- Responsivity: 1 A/W
- Thermal Noise: 3e-12 A/Hz$^{-1/2}$
- Dark Current: 0 A

The fibre spans use non-zero dispersion shift fibre - NZDSF with a dispersion of 5.7 ps/(nm.km), and a slope of 0.037 ps/(nm^2.km). The first two spans have 90 km and the last one 120 km. The others parameters of the DSF are the following:

- Reference Frequency: 193.1e12 Hz
- Attenuation: 0.21e-3 dB/m
- Core area: 80e-12 m^2
- Tau1 – First adjustable parameter for Raman response function : 12.2 e-15
- Tau2 – Second adjustable parameter for Raman response function: 32. e-15

The amplifiers are modelled using AmpOpt_DSM, which include the spectral gain and noise characteristics from file, plus a 7.3 –km length of dispersion-shifted fibre which has been designed to compensate for the slope of the transmission fibre. The power is set-up to 21 dBm, the noise figure is 5 dB and the noise center frequency is 193.1e12 Hz. The DCF fibre has the following characteristics:

- Reference Frequency: 193.1e12 Hz
- Attenuation: 1.05e-3 dB/m
- Dispersion 16e-6 s/m^2
- Dispersion slope: - 0.52e3 s/m^3
- Core area: 50e-12 m^2
- Length: 2 e3 m
- Tau1 – First adjustable parameter for Raman response function : 12.2 e-15
- Tau2 – Second adjustable parameter for Raman response function: 32. e-15

The booster amplifier used is characterised by the following parameters:

- Unsaturated Gain: 10 dB
- Saturation power: 10 e –3 W
- Noise Figure: 4 dB
- Noise Center Frequency : 193 e12 Hz
- Noise Bin Spacing: 0.1 e12 Hz

Finally to equalize the dispersion in the detected channel we use a single mode fibre - SMF characterised by the following parameters:

- Reference Frequency: 193.1e12 Hz
- Attenuation: 0.21e-3 dB/m
- Dispersion 16e-6 s/m^2
- Dispersion slope: 0.08e3 s/m^3
- Core area: 80e-12 m^2
- Length: 12e3 m
- Tau1 – First adjustable parameter for Raman response function : 12.2 e-15
- Tau2 – Second adjustable parameter for Raman response function: 32. e-15

3. Simulation results

The simulations [1] was done based on the PTDS (Photonic Transmission Design Suite) – software simulator produced by Virtual Photonics Inc (www.virtualphotonics.com).

Two modes of simulation exist in PDTS***:*** *sample mode and block mode. Sample Mode* is used for bi-directional simulation of closely coupled components. *Block Mode* passed data as arrays of the complex envelope of the optical field; restricting bidirectionally to components spaced by more than a block length, such as optical switches separated by fibre [5].

Sample mode has a single signal representation, covering all simulated optical frequencies and assuming a single polarisation.

Block mode has both sampled and statistical signals, containing polarisation information and centre frequency, allowing a simulation to be portioned spectrally into appropriate signal representations as follows.

- A single frequency band (SFB) can be used to cover all data channels, or individually using multiple frequency bands (MFB's), each with a centre frequency and each covering one ore more channels.
- Noise Bins (NB's) represent broad noise spectra efficiently as a mean power spectral density within a defined frequency range. NB's are effective for the amplified spontaneous (ASE) in an optical amplifier.

The simulation [2] is initially set up for Parameterized Signals in all bands. This will not give an eye diagram. However, changing the *OutputDataType* of the top set of channels to Block will cause this band to be represented by an SFB. An eye will be produced for the 10^{th} channel.

The output spectrum of the transmitted channels is shown in Fig. 2 [3], with 80 Parameterized Signals. The Resolution Bandwidth has been set to 12.5 GHz to indicate the OSNR into 0.1 nm directly. The noise is propagated in both polarizations.

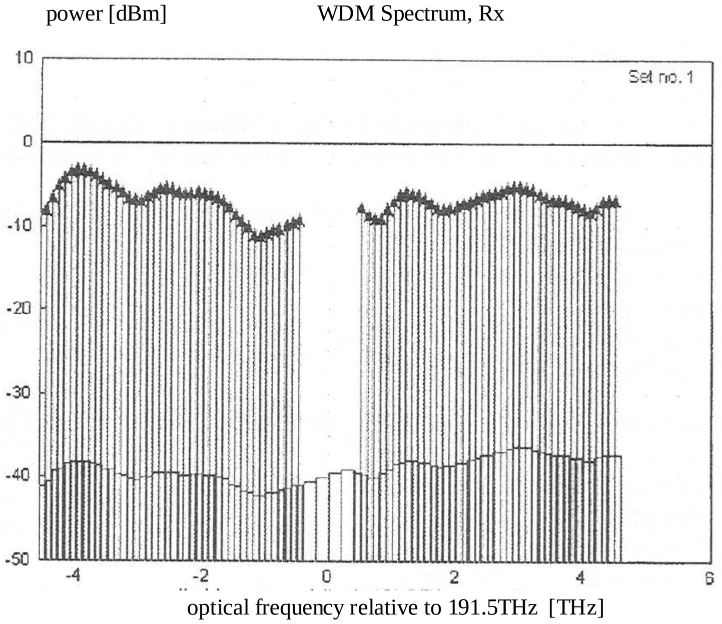

Fig. 2. The output spectrum showing Parametrized Signals and Noise Bin.

Simulation with an SFB

Any band can be set to be represented by a SFB, by setting the OutputDataType of that transmitter to be Blocks. However, the receiver filter and the channel label have been set to accept the 10^{th} channel from the top transmitter array. Noise is propagated separately as Noise Bins to allow a single-polarisation fibre model to be used.

The eye diagram shown in Fig. 3 [3] include dispersion, nonlinearity, amplifier and receiver noise, and bandwidth effects. Strong overshoots in the 1-level indicate the effect of Four-Wave Mixing producing in-band tones, which mix with the desired signal. Reasonably good eye opening was demonstrated.

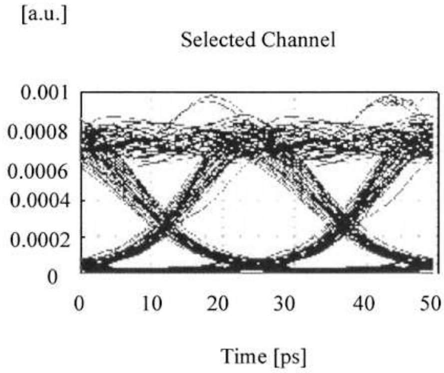

Fig. 3. Eye diagram including dispersion and fibre nonlinearity.

The BER – bit error rate can be activated to estimate the end-to-end error performance of the worst channels. Fig. 4 [3] shows typical plot timing, as produced by the BER module.

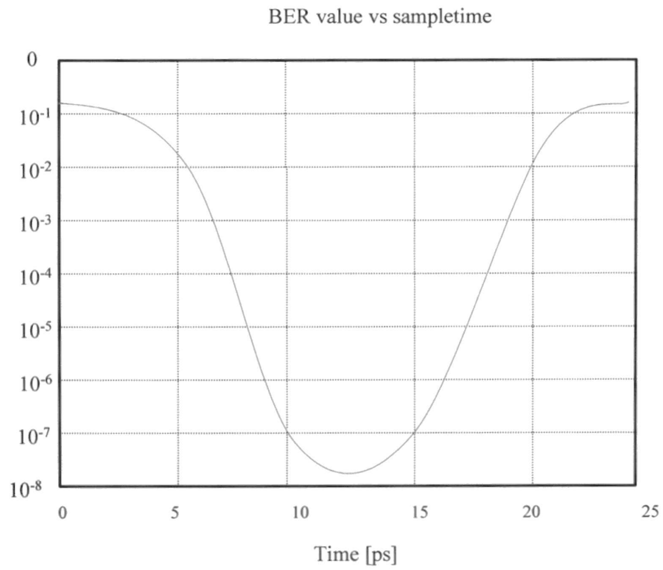

Fig. 4. BER versus timing as produced by the BER module when the Visualize option is activated.

Fig. 5 shows the system Q simulation result after 3-span transmission. The variation of Q with wavelength was mainly due to the channel power saturation. This Q factor was obtained using a pattern length of 2^{31}-1.

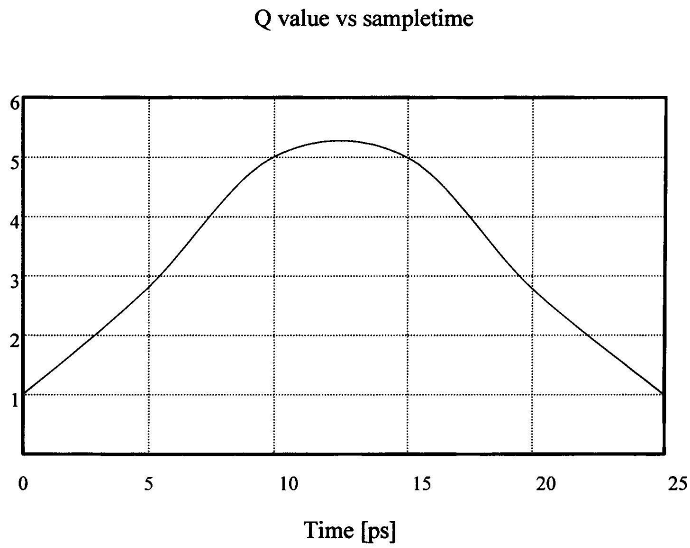

Fig. 5. Q-Factor vs timing.

4. Conclusion

We successfully demonstrated transmission of 80 carrier channels at 40 Gbit/s with 100 GHz channel spacing and a record amplifier spacing of 90-and-120 km over 400 km. Raw Q-Factors between 5 to 6 were demonstrated for all 80 channels in the absence of forward error correction. The large amplifier spacing was achieved without using optical regeneration.

References

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