High capacity WDM transmission in the 1310 nm wavelength domain for the RETINA network purposes

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One of the options for the RETINA network, part of the LOFAR antenna system, is to use the 1310 nm wavelength domain for transmission of data from antenna stations to the central processor. We demonstrate successful 80-Gbit/s (4×20-Gbit/s) WDM transmission in the 1310 nm wavelength domain over a distance suitable for the LOFAR antenna system. Additionally, we verified the feasibility of a 160-Gbit/s (8×20-Gbit/s) transmission over the same distance. In all cases the Q factors exceed 17.2 dB, corresponding to BER values under 10^{-12}.

Introduction

To observe events far away in the universe, high-performance radio telescopes are needed. The innovative Low Frequency Array (LOFAR) antenna system uses 13104 separate antennas, spread out in an area with a diameter of approximately 350 km [1]. The radio signals captured by the individual antennas are digitized and transported to a central signal processor. The aggregate data flow rate to the processor is some 26-Tbit/s.

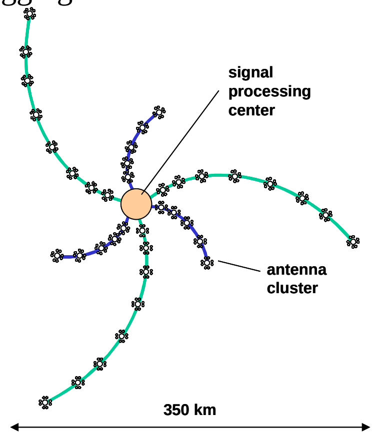

Figure 1 The LOFAR antenna system

Figure 1 shows that stations will be arranged in a central area of 2 km in diameter, along three short (about 65 km), and three long (about 250km) curved arms, which converge in the central area. Table 1 summarizes LOFAR antenna system configuration.

Number of antennas	13104	Diameter 200m, 78 antennas/station
Data rate per station	160-Gbit/s	Full data rate from 78 antennas
Full LOFAR data rate	26-Tbit/s	Full data rate entering the central processor
Distribution along the arms	3*14=42	In three short arms of 65 km length
	3*28=84	In three long arms of 250 km length

Table 1 The LOFAR antenna system configuration [1]

The goal of the Remote Elements Telescope Intelligent Network Architecture (RETINA) project is to investigate the optical fibre network, needed to transport the huge data streams to the central processor in the LOFAR antenna system. Various combinations of the Wavelength Division Multiplexing (WDM) and Optical Time Domain Multiplexing (OTDM) techniques are under investigation.

One of the possibilities in the short arms is to use the 1310 nm wavelength domain for WDM transmission (8×20-Gbit/s), which has the advantage that it can be used as a dedicated wavelength band in parallel to the 1550 wavelength domain. One of the most important features of the 1310 wavelength domain, for considered distances and bit rates, is the virtual absence of the dispersion-related system penalties, alleviating the need for dispersion compensation.

Experimental set up

The transmitter consisted of four DFB lasers operating in CW conditions. The lasers were operating at the wavelengths: 1308.35 nm, 1309.22 nm, 1310.61 nm, and 1311.79 nm. We made use of an unequal channel spacing allocation scheme to assure the elimination of the FWM related penalties. All four signals were combined in a 4×2 power coupler and then simultaneously modulated in an external Mach-Zender modulator at the bit rate 20-Gbit/s with 2^{31}-1 PRBS pattern length. The SOA #1 amplified all signals after the modulator. Next the signals passed through 5 km of DSF to decorrelate the bit patterns of different channels. A direct-modulated laser module operating at 1315.84 nm, was driven by a 10-Gbit/s PRBS electrical signal. Finally a 3 dB coupler combined the 10-Gbit/s signal and the 4×20-Gbit/s signals.

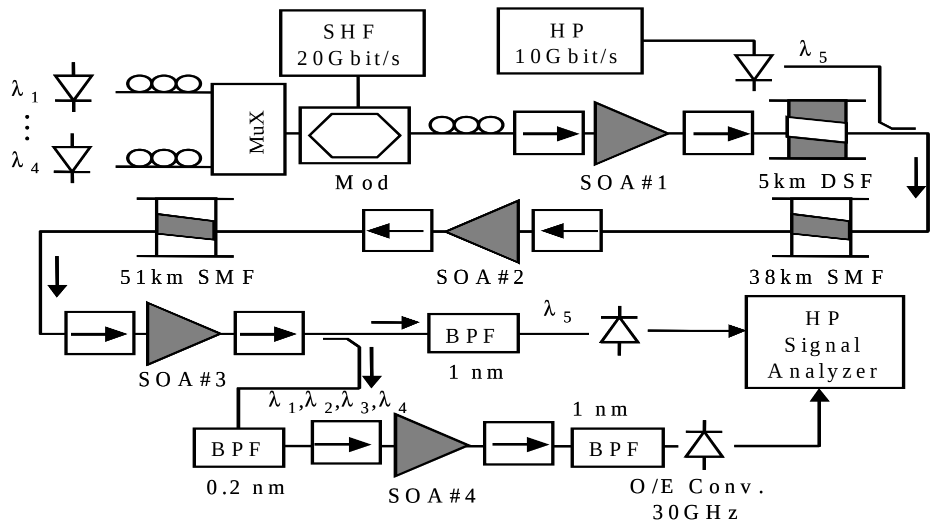

Figure 2 4×20-Gbit/s experimental set-up

The transmission links consisted of two fiber spans and one in-line SOA #2 placed between them. The length of the first fiber span was 38 km and the second span 51 km. The average attenuation value at 1310 nm is 0.32 dB/km, and the dispersion value at the same wavelength is equal to -2.6 ps/nm/km.

Two receivers were used in the set up. One receiver detected 10-Gbit/s signal and the second one 20-Gbit/s. In the first stage of the receiver SOA #3 amplified all signals together. The next 3 dB coupler split the signal power into two paths. The 10-Gbit/s path consisted of a 1 nm bandpass filter and the 10-Gbit/s receiver module. In the 20-Gbit/s path we used two bandpass filters of 0.2 nm and 1 nm respectively, and placed between them SOA #4. After the 1 nm bandpass filter we placed a photodiode. We connected directly the photodiode to the digital communication analyzer to perform Q factor measurements.

For feasibility studies of 8×20-Gbit/s WDM the setup was modified by increasing the optical power of the 10-Gbit/s channel by a factor of 8dB. This power increase emulated at least four additional WDM channels.

Results

Fig. 3 shows the WDM spectra taken by an optical spectrum analyzer at the point before and after the 90-km transmission.

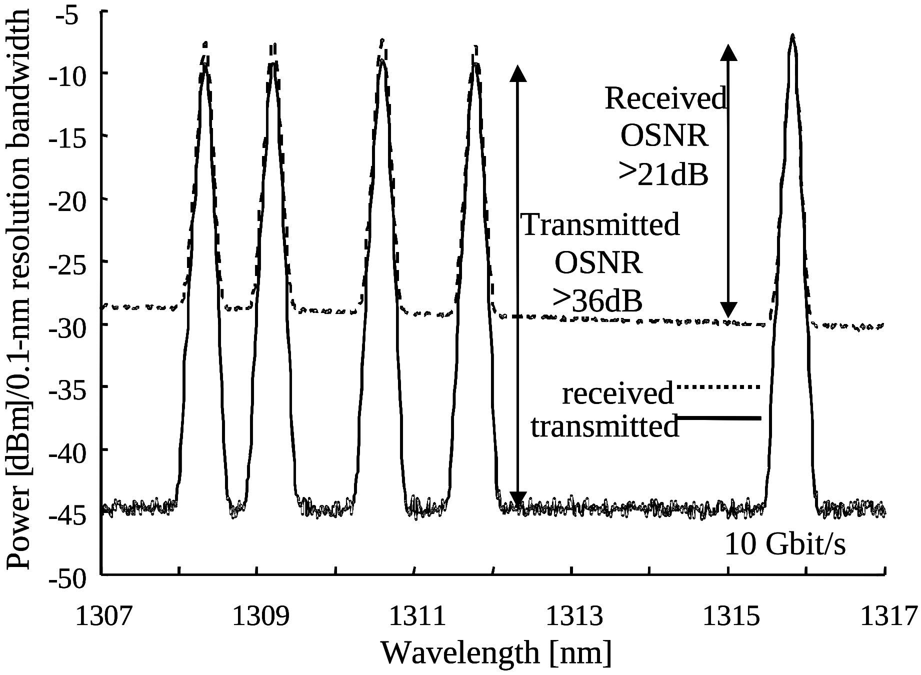

Figure 3 Transmitted and received spectra. Optical Signal to Noise Ratios are better than 21dB

We evaluated the system performance by Q factor measurements. We performed the Q factor measurements directly on a scope. Table 2 summarizes measured Q factor values in two cases: before and after increasing the power of the 10-Gbit/s channel. Additionally Table 2 contains the calculated average value of the Q factor (Q_{av}).

	Before increasing the power of 10-Gbit/s channel		**After increasing the power of 10-Gbit/s channel**	
Channel	**Q**	Q_{av}	**Q**	Q_{av}
I	17.8, 17.8, 17.6, 17.8	17.8	17.4, 17.5, 17.2, 17.2	17.3
II	17.5, 17.5, 7.7, 17.8	17.6	17.2, 17.6, 17.4, 17.2	17.4
III	17.7, 17.4, 17.8, 17.7	17.7	17.6, 17.3, 17.3, 17.4	17.4
IV	18.3, 17.9, 18.1, 18.2	18.1	17.6, 17.7, 17.2, 17.2	17.5

Table 2 Q factor values for all data channels before and after increasing the power of the 10 Gbit/s channel

Fig. 4 presents eye diagrams captured during the Q factor measurements.

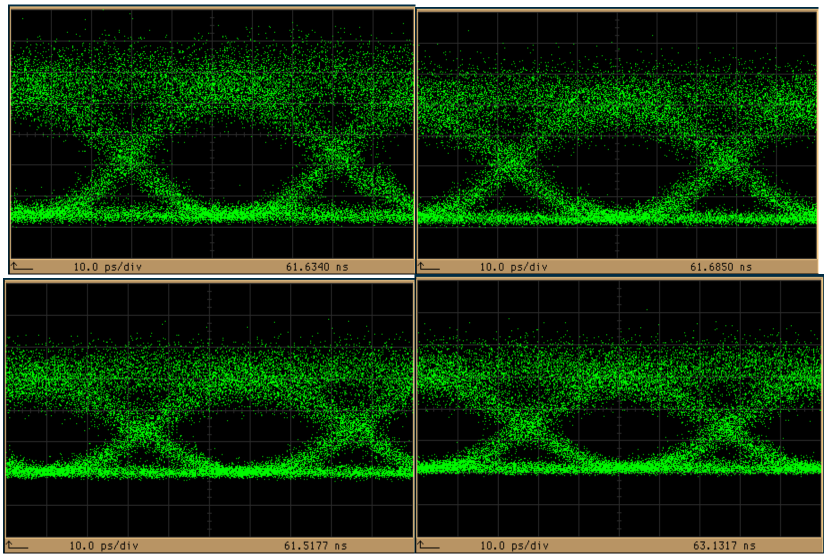

Figure 4 Eye diagram of channel 1 (upper row) and 3 (lower row) carrying 20-Gbit/s NRZ PRBS data: before (left column) and after (right column) increasing power of 10-Gbit/s channel

Discussion

Accumulation of Amplified Spontaneous Emission (ASE) leads to OSNR degradation. The OSNR for all four 20-Gbit/s channels after the transmitter was equal to 36 dB and 38 dB for the 10 Gbit/s channel. After SOA #3 the OSNR for all five channels was ≥21 dB.

The Q factor value for all the channels in all cases was higher than 17.2 dB. This Q factor values corresponds [2] to a BER value of 10^{-12}, when Gaussian noise dominates the receiver noise. Figure 4 presents captured eye diagrams. The logical one level is distorted more than the logical zero level. These distortions are caused by the beat of the signal with the accumulated ASE noise and the residual non-linear effects e.g. cross gain modulation in the SOAs. The center of the eye diagrams is clear form distortions and the eye opening is large enough to perform an error-free transmission. The right column eye diagrams, captured after increasing the power of the 10-Gbit/s signal, exhibit a small decrease in the output amplitude. This is caused by the drop in the optical power per channel due to the gain suppression in the saturated SOAs.

Conclusions

Taking into account the results of the experiments we proved hat 160-Gbit/s WDM transmission in the still unexploited 1310 nm window for the RETINA network purposes is possible.

Acknowledgement

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References

[1] A.M.J. Koonen et al. A very high capacity optical fibre network for large-scale antenna constellations: the RETINA project. In NOC, 2001.

[2] G. Keiser, Optical Fiber Communication, McGraw-Hill, 2000.