Experimental Verification of the Dispersion Tolerance Improvement of Partial DPSK with Optimised Filtering.

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Abstract We experimentally confirm the optimum combination of modular delay and filter bandwidth to maximize the dispersion tolerance of partial DPSK.

Introduction
Differential phase shift keying (DPSK) is an important modulation format because of its suitability for high data rate systems. This is mainly due to its improved optical signal to noise ratio (OSNR) performance compared to on-off keying (OOK). It is therefore important to identify possible ways of improving DPSK tolerance to other impairments present on optical communication systems, such as chromatic dispersion and strong optical filtering.

It has been numerically shown recently that partial demodulation, where the delay between the arms of the Mach-Zehnder delay interferometer (MZI) demodulator is reduced to less than one bit period increases significantly the chromatic dispersion tolerance provided that an appropriate optical filter is selected. This is also associated with the improved filter tolerance of this so called partial DPSK which makes possible improved spectral efficiency and the use of 40G DPSK in 50GHz separated WDM systems. Reference [2] showed that in order to gain the full benefit from partial DPSK it is essential to match the correct filter bandwidth, which was shown to be somewhat narrower than the bandwidth used in most cases, and the correct delay.

In this experiment we used a Mach-Zehnder interferometer with a fully tuneable delay (from Kylia) and a bandwidth tuneable filter, to confirm the results of previous modelling and can identify the best combination of delay and filtering for a range of dispersions for the first time.

System under test
The system used to carry out the experiment is shown in Figure 1. This consists of a pattern generator which drives a Mach-Zehnder modulator with 2^31 – 1 PRBS followed by a pulse carving MZ-modulator to generate a 67% RZ DPSK signal at 43Gbit/s. Noise is then added to the optical signal and the resultant signal plus noise passes through a tuneable dispersion module. The signal is then filtered, goes through the tuneable MZI and is finally received using a balanced detector.

Results
The system described above was investigated with net dispersions of 0, 75 and 100ps/nm. In order to get useful results for all the dispersion values mentioned, the OSNR was set to 20.8dB (in a 0.1nm bandwidth) and the signal power at the receiver was kept at 2dBm. Measurements were taken for values of MZI delay varying from 40% to 100% of a bit period and filter bandwidths varying from 31.2GHz to 80.0GHz.

The effect of optimizing the filter bandwidth and the delay of the MZI can be seen in the plots in Figure 2. The upper plot shows the BER contour plotted against filter bandwidth and normalised delay for 0 ps/nm (top) and 100 ps/nm (bottom)
the optimum receiver has a delay of 1 bit and a large filter bandwidth of ~70GHz. The lower plot shows the BER contour after passing through a dispersion of +100ps/nm. This figure shows clearly that the optimum BER is obtained for a delay 70% of a bit period and the filter bandwidth of ~50GHz.

Figure 3 compares the experimental results found here with modelling results from a previous publication. The optimum delays found (marked by the solid shapes, triangles for modelling and squares for experiment) show excellent agreement with the modelling results. The relationship between optimum delay and dispersion is linear as can be seen from the line fitted to the modelling results. The optimum filter bandwidths (open shapes) are also generally a good match although the different filter profiles used in the modelling and the experiments make close comparison less easy in this case. In particular the filter bandwidth for zero dispersion is much broader for the modelling results than found in the experiments; however when there is dispersion present the modelling and experimental results are a closer match.

Discussion
The main advantage from using DPSK instead of OOK comes from a 3dB receiver sensitivity improvement. When a DPSK signal is received without a delay interferometer, or equivalently an MZI with no relative delay between the two arms, and with strong filtering it can be directly detected as a duobinary signal. When this is done balanced detection cannot be used and so the 3dB benefit from using DPSK is lost. If the relative delay in the MZI is reduced from one bit period and the filter bandwidth is narrowed the signal is partially converted into a duobinary signal which has large dispersion tolerance and narrow bandwidth making this format particularly suitable for high pass dispersion uncompensated metro or local networks. In fact when a DPSK signal is received with one bit delay, the destructive port of the MZI, that acts as a first order high pass filter, shows a modified duobinary or alternate-mark inversion (AMI) signal while the constructive port, that acts as a first order low pass filter, shows a duobinary signal. As the signal converts to duobinary, there is a reduction in the OSNR performance as there is no longer perfectly balanced detection.

It can be seen from the plots in Fig. 2 that although with dispersion there is a benefit from using partial-DPSK when no dispersion is present there is a penalty. To see this, it is enough to notice that in the case where no dispersion is present (graph on the top), the best performance is observed in the top of the graph, where the delay between the arms of the MZI is one bit period, while in the case where dispersion is present (graph on the bottom), the best performance is observed around the central zone of the graph, which corresponds to a delay lower than a bit period and therefore to a partial-DPSK signal.

Conclusions
We have confirmed experimentally that by optimizing the delay of the MZI demodulator and the filter bandwidth at the receiver of a DPSK system it is possible to obtain significantly improved dispersion tolerance. In this paper we have demonstrated this experimentally by fully optimizing both the filter bandwidth and the amount of delay used in the MZI to maximize the dispersion tolerance. To the best of our knowledge this is the first time a full range of delays has been used in an experiment. The plots in figure 3 show that previous modelling results accurately predicted the optimal delay and filter bandwidths for a range of residual dispersions.

References
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