Demonstration of 10Gbit/s transmission over 900km SMF with <400ns adaptation time using full-field EDC

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Abstract: We significantly extend the reach of 10Gbit/s on-off keying single-mode fibre transmission using full-field based electronic dispersion compensation (EDC) to 900km. In addition, the EDC balances the complexity and the adaptation capability by employing a simple dispersive transmission line with static parameters for coarse dispersion compensation and 16-state maximum likelihood sequence estimation (MLSE) with Gaussian approximation based channel training for adaptive impairment trimming. We report improved adaptation times of less than 400ns for a bit error rate target of 10^{-3} over distances ranging from 0km to 900km.

Introduction: Recent advances in high-speed microelectronics have enhanced the practicality of electronic dispersion compensation (EDC) [1-6] for optical communications. Conventional EDC [1-2] uses direct detection, so has limited performance due to the loss of the phase information. EDC based on coherent detection has various advantages [6]. However, it is still expensive, requiring an additional narrow-linewidth laser, two 90^0 hybrids, and four balanced detectors.

Full-field detection based systems [3-5], which extract the optical field using a non-coherent optical receiver and electronic field reconstruction, greatly reduce the complexity. This non-coherent optical receiver consists of an asymmetric Mach-Zehnder interferometer (AMZI) and two photodiodes. Maximum likelihood sequence estimation (MLSE) using full-field reconstruction [3] has been shown to exhibit around 50% performance improvement when compared to conventional direct-detection MLSE, but its complexity grows exponentially with fibre length. On the other hand, full-field EDC using a dispersive transmission line is simple, and transmission over 500km single-mode fibre (SMF) has been demonstrated [4]. However, this technique is based on static compensation.

In this paper, we greatly extend the reach of a full field EDC based on-off keying (OOK) system to 900km, and demonstrate that adaptation times of less than 400ns are achievable. This maximum transmission distance almost doubles that of previous works [3-4], and is achieved through the use of components with near-optimized parameters and the use of a reduced amplifier spacing of 60km. In addition, the combination of the static dispersive transmission line and 16-state MLSE presented in this paper balances the complexity and the adaptation capability. The MLSE implemented for this paper uses the Gaussian approximation based channel training in contrast to the lookup table used in [3], and we show that this approximation operates well with full-field EDC, and reduces the adaptation time to less than 400ns for a wide distance range of 0-900km.

Experimental Setup: Fig. 1 shows the experimental setup. A 1550nm signal from a distributed feedback laser was intensity modulated using a Mach-Zehnder modulator giving a 6dB extinction ratio signal at 10Gbit/s with 2^{15}-1 PRBS data. A low extinction ratio was used to suppress the noise amplification during full-field reconstruction [5]. The OOK signal was transmitted over a re-circulating loop comprising 60km of SMF with a signal launch power of -2.5dBm per span. A 1nm optical band-pass filter (OBPF) was used in the loop to suppress the amplified spontaneous emission (ASE) noise. At the receiver, the optical signal was detected with an optically pre-amplified receiver and a variable optical attenuator was used to vary the input power to the erbium doped fibre amplifier (EDFA). The pre-amplifier was followed by an OBPF with a 3dB bandwidth of 0.2nm, a second EDFA, and another OBPF with a 3dB bandwidth of 0.8nm. Then the optical signal was passed through a Kylia AMZI with

40ps differential time delay and $\pi/2$ differential phase shift. Note that this delay was close to the optimized value as predicted in [5]. The two outputs of the AMZI were detected by two 10Gbit/s receivers. Both detected signals were simultaneously sampled by a real-time oscilloscope at 25Gsamples/s with 8-bit resolution. In off-line processing, an automatic algorithm was used to temporally align the signals from these two receiver chains, locate the position of the training sequence, and re-sample the signals. Note that due to the use of MLSE, the sampling phase was not strictly required to be at the eye centre. The principles of full-field reconstruction and the dispersive transmission line were similar to those in [4]. However, different from [4], the received sequence was serial-to-parallel (S/P) converted to blocks with block size of 256 bits and 8-bit overlap between adjacent blocks for guard interval. The dispersive transmission line was implemented based on block processing using (inverse) fast Fourier transform. The MLSE had 16 states, two samples per bit and used Gaussian approximation based channel training. MLSE presented in this paper used serial processing, but could also be implemented with parallel Viterbi algorithm [7]. 432,000 signal bits were processed for each distance value.

Experimental Results: Fig. 2 shows typical measured bit error rate (BER) as a function of the received optical signal-to-noise ratio (OSNR) for 0, 480, 720, and 900km. In this figure, the parameters of the dispersive transmission line were set to approximately fully compensate the chromatic dispersion (CD), and the training time for the MLSE was 1μs. The inset depicts the recovered eye diagrams after the dispersive transmission line for 900km. The figure shows that the system operated well after 480km and 720km, with 3dB and 4dB OSNR penalty at BER of 10^{-3}, respectively. At 900km, the slope was reduced due to non-ideally suppressed noise amplification [5]. However, the best achievable BER was 1.5×10^{-4}, well below the forward error correction (FEC) limit.

Fig. 2 is based on the assumption that the prior information of the fibre length has been obtained. In practice, this value may not be known and can also vary frequently over a wide range. Fig. 3 shows the performance when the dispersive transmission line was preset to be a fixed value and MLSE was used to adaptively trim the impairments for various transmission distances. The training time of the MLSE was 1μs and the received optical power into the pre-amplifier was -28dBm. Note that the received OSNR was different for different transmission distances, with the case of 900km exhibiting the worst OSNR of 23dB. The figure shows that a BER better than 10^{-3} could be achieved for any measured distance up to 900km when the pre-set value was between 500km and 575km. This figure also implies that the system was insensitive to the exact pre-set dispersion value, so a coarse estimation was sufficient. The pre-set value was set to favour the lower OSNR region (above 450km) unless the residual CD for the back-to-back case exceeded the MLSE compensation range.

To illustrate the adaptation speed of the system, Fig. 4 shows the BER as a function of the allocated training time for three different transmission distances when the dispersive transmission line was pre-set to compensate 550km CD. The figure shows that the performance converged rapidly during the first 200ns for all distances. After 400ns, the BER fell below 10^{-3} even for the longest distance, thus implying the potential value of full-field EDC in frequently configured optical networks.

Conclusions: We have greatly extended the reach of 10Gbit/s OOK transmission using full-field EDC to 900km. Simple and fast-adaptive impairment compensation over a wide distance range of 0-900km has been demonstrated by combining a static dispersive transmission line with a 16-state MLSE using Gaussian approximation based channel training. It is shown that BERs below 10^{-3} and improved adaptation times of less than 400ns were achieved over this distance range.

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Figure captions:

Figure 1: Experimental setup. AOM: acousto-optical modulator.

Figure 2: $\log_{10}$(BER) versus the received OSNR. Inset: eye diagram of the recovered signal after 900km.

Figure 3: $\log_{10}$(BER) versus transmission distance. The dashed line represents no error for the processed signal.

Figure 4: $\log_{10}$(BER) versus the training time.

Figure 1

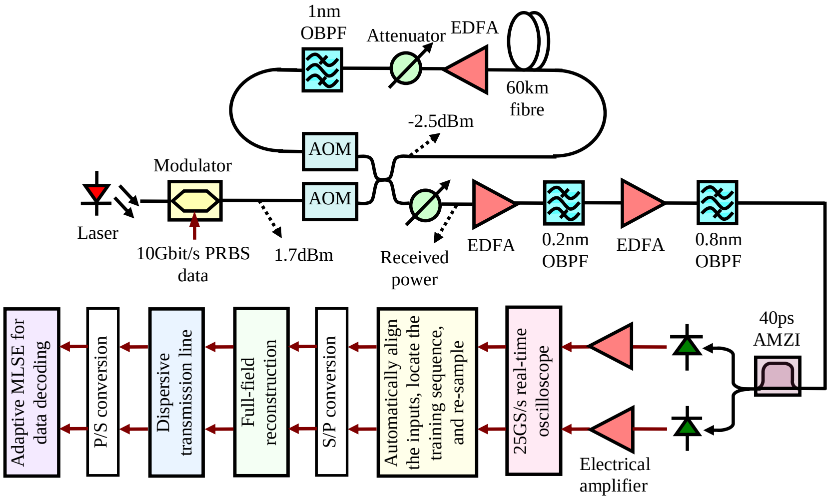

Figure 2

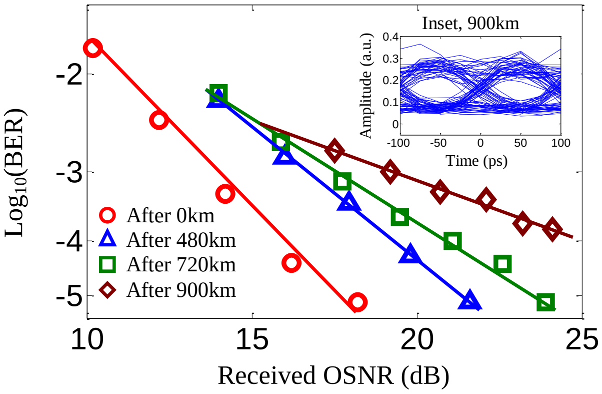

Figure 3

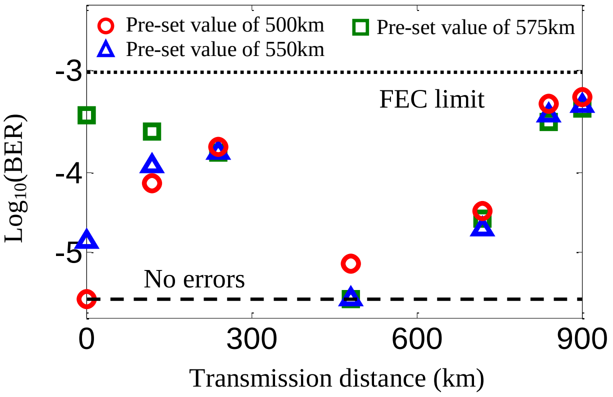

Figure 4