Short-reach 200 Gb/s SDM Network Employing Direct-detection and Optical SSBI Mitigation

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Abstract: We propose a new transmission scheme for direct-detection (DD) short-reach networks based on transmitting the carriers and the data signals in separated cores of a multicore-fibre (MCF). With this scheme, a low complexity signal-signal beat interference (SSBI) mitigation approach is proposed at the receiver side, which may be required to compensate electronically the chromatic dispersion of the singlemode fibre. The performance of a 200 Gb/s binary NRZ signal in a MCF short-reach network employing the proposed transmission scheme is assessed by numerical simulation. The combined effect of the skew and the laser phase noise on the system performance is evaluated. It is shown that the SSBI mitigation technique enables distances up to 180 m when dispersion is not compensated, showing the potential to be implemented in intra data-centre (DC) networks, when the signal mean optical power is much higher than the carrier mean optical power, and when the SSBI estimation is not corrupted by electrical noise. The results also show that in systems with full dispersion compensation, a significant performance improvement is achieved by the proposed SSBI mitigation approach, enabling higher connection lengths.

1 INTRODUCTION

Optical fibre networks are facing an exponential growth on the capacity demands (Cisco, 2018). Space division multiplexing (SDM) technology is pointed out as a solution to overcome the so-called capacity crunch (around 100 Tb/s per fibre) (Butler et al., 2017). Short-reach connections, such as intra data-centre (DC) connections, are experiencing continuous data traffic increase, and this phenomenon brings constrains such as space limitations and the need to maximize the throughput of each connection (Kachris and Tomkos, 2012). Multicore fibres (MCFs) are one of the new technologies brought by SDM. This technology can enhance the network capacity by transmitting data simultaneously on a high number of fibre cores. Recent experiments on MCFs achieved capacities of up to 2.05 Pb/s using a few-mode MCF (Soma et al., 2015) and 2.15 Pb/s using a 22 core homogeneous single-mode (SM) MCF (Puttnam et al., 2015), well beyond the fundamental limit of SM single core fibres. In MCFs, the fibre capacity can be theoretically increased by N times, where N represents the number of independent cores that are incorporated in the same fibre cladding. The number of cores, and the core-to-core distance, will determine the inter-core crosstalk (ICXT) levels. In the particular case of weakly-coupled homogeneous MCFs, different cores of the same fibre present identical core properties and, thus, the ICXT arises due to the coupling between cores. Nevertheless, in short-reach networks, the impact of the crosstalk on the system is reduced due to the small accumulated ICXT. Therefore, this type of MCF presents high potential to be employed in DC connections (Hayashi et al., 2019).

In short-reach networks, low cost and complexity are crucial requirements. Thus, direct-detection (DD) receivers are preferable for these networks since they are cheaper, smaller and less power hungry than coherent detection systems (Cartledge and Karar, 2014). Still, these receivers cause, due to the square law detection of a single photodiode, performance degradation induced by signal-signal beat interference (SSBI) (Ishimura et al., 2019). The SSBI can be mitigated

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using complex digital signal processing (DSP) techniques (Ju et al., 2015), (Nezamalhosseini et al., 2013), which are highly undesired in short-reach networks due to the high costs associated.

In this work, a new transmission scheme based on MCFs and with high potential to mitigate the SSBI with reduced complexity is proposed. This scheme is based on transmitting the virtual carriers, that are used to assist the detection, and the data signals in separated cores of the weakly-coupled MCF. With this, estimation and mitigation of the SSBI at the receiver without resorting to complex DSPs can be achieved. This low complexity SSBI mitigation technique may be of particular interest for DD systems where SSBI mitigation is required at the receiver side prior to employ digital techniques to mitigate the impact of the dispersion impairments on the detected data signal. Also, with the proposed transmission scheme, in which the carriers are transmitted independently from the data signals, additional cost savings may be achieved in bidirectional networks. This occurs because local lasers can be replaced by a single optical comb with carriers being distributed as optical seeds in a single MCF core along the whole network.

The performance of the proposed transmission scheme is assessed by evaluating the impact of the combined effect of the skew and the laser phase noise on the performance of MCF-based short-reach networks. Also, the improvement of the performance due to the SSBI mitigation technique is studied, which can afterwards potentiate the use of simple DSP techniques to electronically remove the dispersion effects on the signal.

2 PROPOSED TRANSMISSION SCHEME

2.1 Concept Description

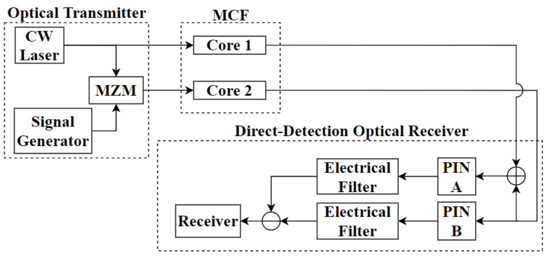


Figure 1: Equivalent model of the MCF-based transmission scheme with DD and SSBI removal.

Figure 1 presents the proposed MCF-based transmission scheme with one core (core 1) dedicated to support only the carriers transmission. The optical transmitter (TX) consists in two branches. One branch generates the optical carrier to be transmitted in core 1. This optical carrier is used at the receiver (RX) side to assist the detection. The other branch generates the optical data signal with carrier suppression. The outputs of the TX are transmitted into two different cores of the MCF. When transmitting data in two different cores, the signals (carrier and data signal) suffer different delays. The relative delay between the signals at the cores output, i.e., the skew, is crucial when adding up the signals. This occurs because the combined effect of the skew and the laser phase noise may lead to destructive interference at the receiver side causing performance degradation.

After fibre propagation, the DD-based RX photodetects the signals performing the optical to electrical conversion. In the positive-intrinsic-negative (PIN) photodiode A, after adding the carrier and the data signal in the RX input, the photodetection of the resulting optical signal is performed. As a result of the photodetection process, an unwanted SSBI term is originated along with the wanted data signal. In PIN B, the carrier suppressed data signal, that the proposed transmission scheme allows to obtain, is photodetected. This allows to estimate separately the SSBI component. Then, this SSBI term is used to subtract the SSBI term originated in PIN A (where the desired signal is located), obtaining, ideally, a SSBI free signal.

2.2 Transmission Scheme Limitations

The performance of the proposed transmission scheme strongly depends on the delay suffered by the signals in different fibre cores, and in particular the skew between the two cores. The relation between the skew and the laser phase noise coherence time, t_c, can provide a solid estimation about how the skew may impact the system performance due to phase noise. The laser phase noise coherence time is given by (Goodman, 2015)

$$t_c = \frac{1}{\pi \cdot \Delta\nu_L} \tag{1}$$

where $\Delta\nu_L$ is the laser linewidth. If the laser electrical field at two different time instants, t and $t+T$, is considered, the coherence time can be defined as the maximum T value for which the phase difference between the electric field at the two instants remains predictable. If t_c is much longer than the skew, the degradation caused by the phase noise is small since the relative delay time between the two cores leads to a situation where, at a given time instant, the phase noise at the output of the two cores has similar amplitudes. In this case, when the carrier is added to the signal, no destructive interference occurs. Contrarily, if t_c is not much longer than the skew, the degradation caused by the laser phase noise can be significant.

Since the DD receiver photodetects each signal through a PIN photodiode, the current associated with the carrier-added data signal (output of PIN A), considering the skew and the laser phase noise, can be written as (for a PIN responsivity of 1 A/W):

$$i_A(t) = |A_c\, e^{j\phi_n(t)} + s(t-T)\, e^{j\phi_n(t-T)}|^2 \quad (2)$$

where A_c is the carrier amplitude, $s(t)$ is the data signal at the MCF output, T is the skew between cores and $\phi_n(t)$ is the laser phase noise.

Based on equation 2, the aforementioned relation between t_c and the skew can be mathematically expressed. If the skew is much shorter than t_c, then

$$e^{j\phi_n(t-T)} \approx e^{j\phi_n(t)} \quad (3)$$

resulting for the current at the output of PIN A:

$$i_A(t) \approx \left| \big(A_c + s(t-T)\big) \cdot e^{j\phi_n(t)} \right|^2 = \left| A_c + s(t-T) \right|^2 \quad (4)$$

In this case, the received signal is not impaired by the laser phase noise. As opposed, in the scenario where t_c is not sufficiently longer than the skew, equation 3 is not verified and so the phase noise is not eliminated when the signal is photodetected, causing phase-to-intensity noise conversion, which will be analysed further on.

One of the main goals of this work is to identify the conditions under which a negligible degradation due to the combined effect of the skew and the laser phase noise is obtained. When the degradation due to the skew and the laser phase is negligible, the current at the output of PIN A is given by (from equation 4, for a PIN responsivity of 1 A/W):

$$i_A(t) = A_c^2 + 2 \cdot A_c \cdot \Re\{s(t-T)\} + |s(t-T)|^2 \quad (5)$$

In this scenario, there are two major impairments that can cause performance degradation: the SSBI (last term) and the chromatic dispersion. The delay, T, is due to the propagation and can be compensated without causing distortion. The dispersion effect is represented in the term $s(t)$ as follows

$$s(t) = s_{in}(t) * h(t) \quad (6)$$

where $s_{in}(t)$ is the data signal at the MCF input, "$*$" is the convolution operator and $h(t)$ is the impulse response of the SM fibre, which contains the attenuation and dispersion effects of the MCF. It is possible to electronically remove the dispersion effects (from Equation 5) through DSP techniques. However, this can be performed only after the SSBI term is removed. This SSBI removal process is analysed in Section 4.

3 SYSTEM SETUP

In this work, a 200 Gb/s polar nonreturn-to-zero (NRZ) signal is considered. A continuous wave (CW) laser generates the optical carrier, affected by the phase noise. The model used to describe the laser phase noise is a Wiener process (Peng, 2010) characterized by the laser linewidth ($\Delta\nu_L$). The NRZ signal is converted into the optical domain using a single-arm chirpless Mach-Zehnder modulator (MZM), biased at the minimum bias point in order to generate the optical signal with suppressed carrier. For the optical transmission, a two core MCF is considered. One core is used to transmit the 200 Gb/s NRZ signal and the other core is used to transmit the carrier. In the case of a wavelength division multiplexing (WDM) system, the optical carriers used to assist the detection of the different NRZ signals would be all transmitted in the same core. The selection of the proper carrier at the RX side is performed after carrier demultiplexing. Linear propagation along each SM core is assumed, with a dispersion parameter of approximately 18 ps/nm/km and a fibre attenuation coefficient of 0.21 dB/km.

Since the RX is based on DD, a single photodetector is considered for each branch. The photodetection is performed by PIN photodetectors with a responsivity, R_λ, of 1 A/W, followed by an electrical filtering using a third-order Bessel filter with a -3 dB cutoff frequency of 160 GHz.

In this IM-DD system, the evaluation of the degradation induced by the system impairments is firstly done by assessing the eye-opening penalty (EOP), which gives a fast estimation of the signal quality, that can reflect the effects of signal distortion and eye closure due to the noise. The EOP is given by

$$EOP = -10 \cdot \log_{10}\left(\frac{I_1 - I_0}{2I_{av}}\right) \quad [\text{dB}] \quad (7)$$

where I_1 represents the lowest current level associated with bits 1 and I_0 represents the highest current level associated with bits 0, both values being taken at the time instant for which the eye-diagram opening is maximum. I_{av} is the detected current corresponding to the average power given by

$$I_{av} = (P_s + P_c) \cdot R_\lambda \quad (8)$$

where P_s is the NRZ signal mean optical power and P_c is the carrier mean optical power, both powers being calculated at the RX input. As $2I_{av}$ is the greatest eye-opening that can be obtained, when $I_1 - I_0$ is equal to $2I_{av}$ the EOP is 0 dB.

To further assess the system performance, by quantifying the impact of the skew, the laser phase noise and the dispersion, the bit error ratio (BER)

- calculated through the direct-error counting (DEC) method - is used as figure of merit. The BER is evaluated before and after SSBI removal results, in order to identify the scenarios in which the proposed SSBI mitigation technique is of particular interest, i.e, when the technique provides system performance improvement.

4 RESULTS AND DISCUSSION

In this section, the impact of the skew, the phase-to-intensity noise conversion and the chromatic dispersion is assessed. This is accomplished by analysing EOP and BER results, evaluating the system performance and the improvement obtained by employing the proposed transmission scheme and SSBI mitigation approach.

4.1 Skew Impact on the Phase-to-intensity Noise Conversion

Figure 2 shows the impact of the skew on the EOP of the detected NRZ signal and how the results are affected by the laser linewidth. The results of Figure 2 consider only the skew and phase noise impairments. A MCF length of 2 km is considered.

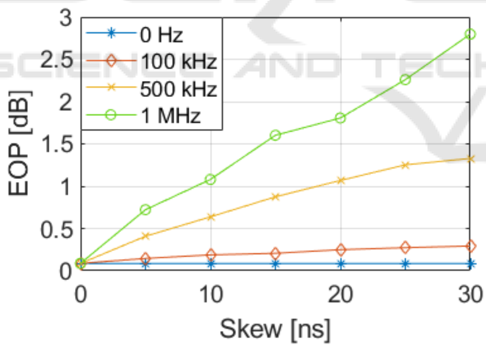


Figure 2: EOP as a function of the skew, for different laser linewidths.

The null linewidth results offer a baseline comparison, allowing to quantify in terms of EOP the impact of the skew compared to the ideal case, where the skew does not impair the system. Different linewidths impact the system performance differently for the same skew. For a skew of 30 ns, linewidths of 500 kHz and 1 MHz show a EOP above 1.5 dB, while the EOP for a linewidth of 100 kHz is not significantly affected by any of the tested skew values.

4.2 Assessment of Beneficial Conditions for SSBI Removal

First and foremost, it is needed to determine under which conditions the proposed SSBI removal approach is effective. The SSBI component is generated from the NRZ signal after photodetection. When the carrier power is much higher than the NRZ signal power, the performance is impaired mainly by the noise levels and the SSBI term is negligible. Otherwise, the system performance is dominantly impaired by the SSBI. From Equation 5, we conclude that the impact of the SSBI term depends on the ration between the carrier and the signal mean optical power.

Figure 3 shows the EOP as a function of the relative power, P_r, defined as the ratio between the signal mean optical power (P_s) and the carrier mean optical power (P_c). The results were obtained with and without considering electrical noise, and for a P_c of 0 dBm.

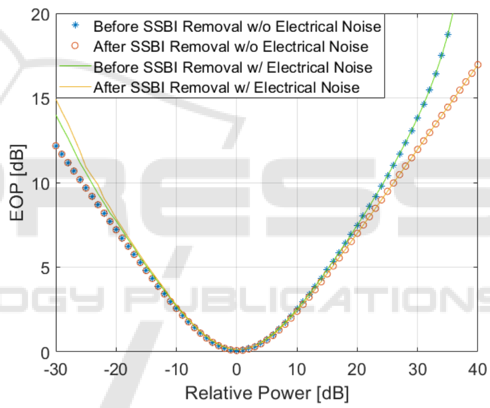
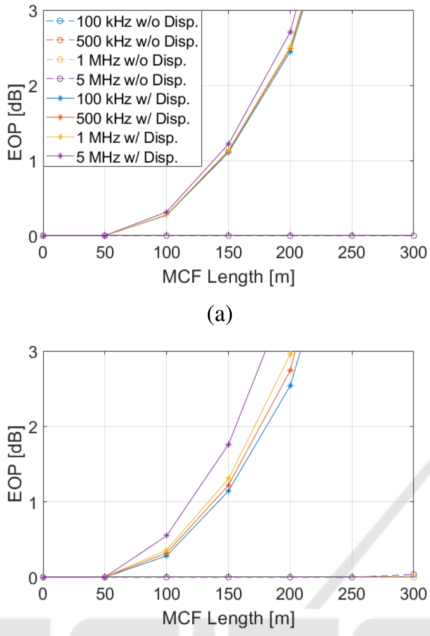


Figure 3: EOP as a function of the relative power, before and after SSBI removal, with and without electrical noise.

When the relative power is lower than 0 dB, the EOP reflects the eye-closure due to the lowering of P_s values. It is also seen that under these conditions, removing the SSBI can worsen the results, in the presence of electrical noise. This happens because when subtracting the output of PIN A with the output of PIN B, in fact two random and independent noise components with the same power are being added. On the other side, for P_r higher than 0 dB, the SSBI removal may show improvements. In this study, for these P_r values, the SSBI term is dominant over the electrical noise power considered, and so the electrical noise does not affect the retrieved signal in terms of the EOP in a visible manner.

Other study is conducted to understand the impact of the dispersion effects on the performance of the system operating at the identified "ideal point", where the signal and carrier mean optical powers are the same. Figure 4 shows the EOP as a function of the MCF length, for different laser linewidths, with and without dispersion considered in the fibre and for a P_r of 0 dB. The walk-off is given as a input parameter to the system instead of the skew.



(a)

(b)

Figure 4: EOP as a function of the MCF length for different laser linewidths, with and without dispersion, for: (a) a walk-off of 1 ns/20 km and (b) a walk-off of 10 ns/20 km.

Results of Figure 4 show that the dispersion clearly constrains the system even if working in the ideal situation (where P_r is 0 dB), showing a minimum of 2.5 dB penalty for all laser linewidths for distances higher than 200 m. For both walk-off values studied, the dispersion is the main impairment responsible for the degradation, but it is noticeable that increasing the walk-off increases slightly the EOP. This happens because increasing the walk-off originates a higher skew for a given distance, and then the combined effect of the skew and the increasing laser phase noise (broader linewidths) leads to an additional performance penalty due to phase-to-intensity noise conversion. From the results in Figure 4, it is possible to conclude that even if considering the P_r that gives the best performance (based on Figure 3), the system is impaired by the dispersion, and this effect overcomes all other effects considered, thus being the most significant. For this reason, if system performance improvement is required, dispersion needs to be fully compensated.

As shown in equation 5, for the dispersion to be compensated electronically at the RX side, the SSBI term needs to be successfully mitigated. As it was seen in Figure 3, an efficient SSBI mitigation only occurs for high P_r. A similar study to the one presented in Figure 3, now considering the BER as the performance metric, is carried out. Electrical noise is again considered, but now it is categorised by the signal-to-noise ratio (SNR), defined as:

$$SNR = \frac{P_{tot}}{P_{noise}} \quad (9)$$

where P_{tot} is the carrier-added NRZ signal mean power at the output of PIN A and P_{noise} is the noise power. From equation 9, given a certain SNR value under test and the mean power of the received signal imposed by P_r, P_{noise} is determined and used to simulate the noise component added after photodetection on both branches (PIN A and B).

Figure 5 shows the BER as a function of the P_r, before and after SSBI removal, for different SNR values. These results were obtained without considering skew, laser phase noise and dispersion, in order to firstly assess the SSBI mitigation technique effectiveness in a more favorable scenario, where only electrical noise is considered. Under these conditions, the SSBI mitigation is not impaired by the phase noise nor the dispersion. Figure 5 shows that the SSBI mitigation for values of P_r under 15 dB only degrades the BER, meaning that, for the SNR values considered, the SSBI estimation is corrupted by the electrical noise and, thus, no effective SSBI mitigation is achieved. In accordance with the results shown in Figure 3, the SSBI removal is not effective for these P_r tested values.

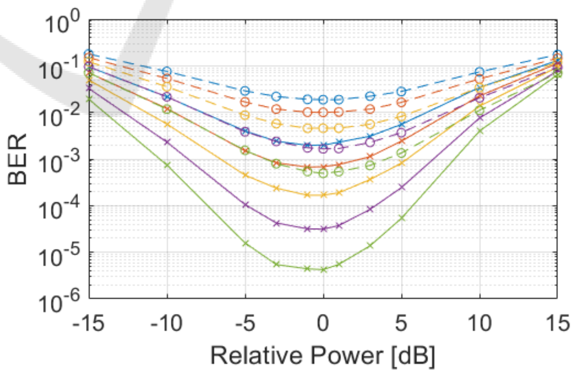
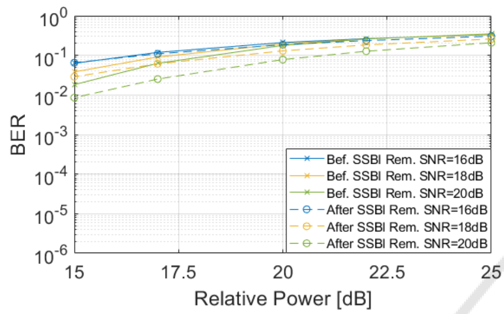
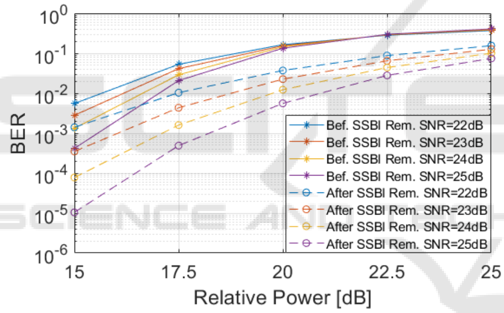


Figure 5: BER as a function of the relative power before (continuous line) and after (dashed line) SSBI removal for a SNR of: 12 (blue), 13 (red), 14 (yellow), 15 (purple) and 16 (green) dB.

In Figure 6, an extension of Figure 5 to relative powers between 15 and 25 dB is shown. With this, system situations in which the SSBI is more powerful are tested. The sub-figures of Figure 6 consider two different sets of SNR values that were tested. When the SNR is increased, converging to a ”no-electrical noise” scenario, a BER improvement is obtained after SSBI mitigation. This indicates that, under these conditions (SSBI mitigation not corrupted by electrical noise), it is possible to effectively estimate and mitigate the SSBI. Given that, and bearing in mind that further on it may be wanted to compensate the dispersion effect on the signal, we need to operate in the referred P_r and SNR values, since the dispersion compensation process directly depends on a successful SSBI mitigation.



(a)



(b)

Figure 6: BER as a function of the relative power before (continuous line) and after (dashed line) SSBI removal, for two different sets of SNR values.

Following the results obtained in Figure 6, the evaluation on the SNR improvement before and after SSBI removal may be done. This is performed for a targeted BER of 10^{-3}, and only considering the effect of electrical noise (no skew nor dispersion effects are considered). The SNR improvement required is defined as the difference, in dB, between the SNR needed to obtain a BER of 10^{-3} before SSBI removal and after SSBI removal.

Figure 7 shows the SNR improvement required as a function of the signal mean optical power, for different carrier mean optical powers. Figure 7 shows once more that the SSBI removal is only effective when the NRZ signal mean optical power is much higher than the carrier mean optical power. Additionally, results of Figure 7 show also that the key factor to obtain a certain SNR improvement is the power relation (P_r) between the data signal and the carrier, and not the absolute mean optical power values of these signals. As an example, 6 dB improvement on the required SNR to achieve a BER of 10^{-3} may be achieved with $P_c = 0$ dBm and $P_s = 18$ dBm, or with $P_c =$ -10 dBm and $P_s = 8$ dBm. For this reason, the studies presented in the following subsections are realized considering $P_s = 18$ dBm and $P_c = 0$ dBm.

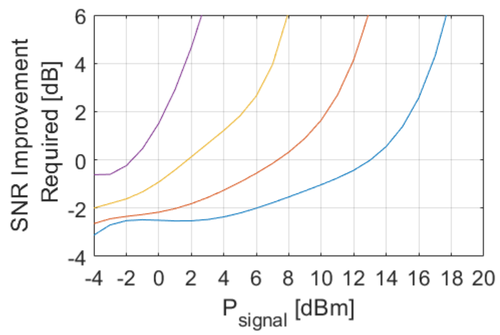


Figure 7: SNR improvement required as a function of the NRZ signal mean optical power, for different carrier mean optical power levels: 0 dBm (blue), -5 dBm (red), -10 dBm (yellow) and -15 dBm (purple).

4.3 Skew Impact on the System Performance

In this subsection, the degradation induced in the BER by the combined effect of the skew and the laser phase noise is studied for different laser linewidths. As a reference, Table 1 indicates the coherence time of each laser linewidth considered in this subsection.

Table 1: Coherence time for different laser linewidths.

Laser linewidth [MHz]	t_c [ns]
0.1	3183
0.5	636.6
1	318.3
5	63.66

Figure 8 shows the BER before and after SSBI removal as a function of the SNR with $P_r = 18$ dB, for different skew values and for the laser linewidths indicated in Table 1.

Figure 8 (a) shows that, for a laser linewidth of 100 kHz, the impact of the skew on the system performance is negligible. By analysing the t_c (see Table 1) obtained for a 100 kHz linewidth, it can be seen that the coherence time is much higher than the skew values under test (approximately 100 times higher than 30 ns). So, the skew effect on the phase-to-intensity noise conversion is low. Figure 8 (a) enables also to conclude that for the 100 kHz laser linewidth, a BER of 10^{-3} is reached for all skew values considered, for a SNR of 25 dB, when SSBI mitigation is employed.

When increasing the laser linewidth and thus decreasing the respective t_c, the system performance becomes more sensitive to the skew. As it can be seen in Figure 8 (b) (linewidth of 500 kHz), the curves corresponding to the SSBI removal results start to show the effect of the laser phase noise. When increasing the skew, it can be seen that the BER starts to increase as well. Still, the coherence time corresponding to the 500 kHz linewidth is 21 times higher than the longest skew considered. So, although the effects are felt, they are not excessively degrading the system performance. For this laser linewidth, a SNR of at least 26 dB guarantees a BER lower than 10^{-3} for all skew values tested.

Figure 8 (c) shows that the skew effect on the phase-to-intensity noise conversion starts to become significant for a linewidth of 1 MHz, degrading the system performance. For a skew of 30 ns, the coherence time corresponding to 1 MHz laser linewidth is only 10 times longer than the skew. So, it is expected (and proven by the results), that the degradation due to the phase noise severely impacts the system. For a skew of 30 ns, it is not possible to reach a BER lower than 10^{-3} after SSBI mitigation. In contrast, the laser linewidth of 1 MHz can provide a BER lower than 10^{-3} after SSBI removal, for SNR values of or above 26 dB, up to a skew of 15 ns. It is worth noting that for a skew of 15 ns, the results are identical to the results obtained for a skew of 30 ns and the 500 kHz linewidth. For both these cases, the relation between the skew and the laser's coherence time is the same, being the coherence time 21 times higher than the skew.

Figure 8 (d) shows the BER results for a laser linewidth of 5 MHz. Results of Figure 8 (d) show that the 5 MHz linewidth has very low tolerance to the increasing skew values. For the results presented in Figure 8 (d), the benefits of employing the proposed SSBI mitigation approach occur only for a skew of 1 ns. For 15 and 30 ns skew, the SSBI mitigation technique is not effective due to high levels of phase-to-intensity noise conversion. Bearing in mind the coherence time corresponding to 5 MHz linewidth, and taking into account the results described throughout this subsection, it is possible to deduce that a laser with a linewidth of 5 MHz only tolerates a degradation caused by phase-to-intensity noise conversion for a maximum skew of 3 ns. In this case, the coherence time corresponding to the 5 MHz linewidth is 21 times higher than the 3 ns skew, which, as seen before, guarantees a BER under 10^{-3} for SNR values exceeding 25 dB.

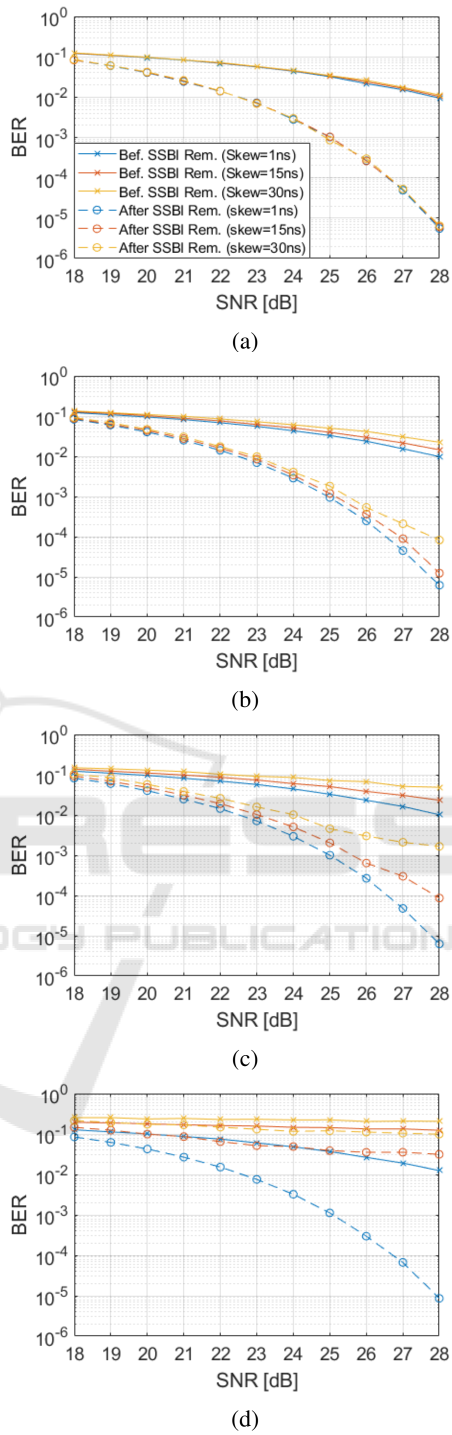


Figure 8: BER as a function of the SNR before (continuous line) and after (dashed line) SSBI removal considering different skew values, for a laser linewidth of: (a) 100 kHz, (b) 500 kHz, (c) 1 MHz and (d) 5 MHz.

4.4 Dispersion Impact on the System Performance

In this subsection, the impact of the chromatic dispersion on the system performance is evaluated, in the presence of skew and laser phase noise. From the study of subsection 4.3, the SNR values required for a BER lower than 10^{-3} were identified. So, this study is performed for a SNR of 26, 27 and 28 dB; for lower SNR values, the BER after SSBI removal is higher than 10^{-3}, showing no interest for the scenarios under evaluation. The laser linewidths chosen for this study are 100 kHz and 5 MHz.

Figure 9 demonstrates the dispersion and skew impact on the BER. Each set of curves are composed by 3 lines, which represents a SNR of 26 dB (higher BER of each set), 27 dB and 28 dB (lowest BER of each set). The results were obtained in the following conditions: before SSBI removal with dispersion (continuous line) and without dispersion (dashed and dotted line); after SSBI removal with dispersion (dashed line) and without dispersion (dotted line), in order to evaluate how differently each impairment impacts the system. A walk-off of 10 ns/20 km was considered.

Figure 9 (a) shows the BER as a function of the MCF length for a laser linewidth of 100 kHz. Comparing with Figure 9 (b), which shows the 5 MHz linewidth results, it is possible to conclude that very similar results are obtained. In presence of dispersion, both linewidths surpass a BER of 10^{-3} for fibre lengths longer than 180 m after SSBI removal for the most favorable case (SNR of 28 dB). In contrast, the results that emulate an ideally compensated dispersion environment (dotted and dashed and dotted lines - null total dispersion) show that the BER remains practically unchanged for the tested length. Under these conditions, the phase-to-intensity noise conversion is the only effect impacting the system performance, and the results in Figure 9 (a) and (b) show that, for the tested walk-off and fibre lengths, the system performance is weakly affected, regardless the analysed laser linewidth. As an example, for 300 m of MCF length, we have a skew of 0.15 ns, which, as has been shown in subsection 4.3, is not enough to degrade the system performance due to phase-to-intensity noise conversion. These results show that, in presence of dispersion, the results before and after employing SSBI mitigation rapidly converge, as the fibre chromatic dispersion significantly degrades the system performance. However, when the dispersion is compensated, promising results can be achieved when SSBI removal is performed. In order to compensate for the dispersion, the SSBI component needs to be suppressed. This can successfully occur when a high P_r is used, since a BER performance improvement before and after SSBI removal is only achieved under those conditions.

Figure 9 results help to emulate a real-use scenario, where dispersion and walk-off are inherent effects of the fibre. When dispersion compensation is not employed, the maximum link length reached is between 100 and 180 m (for the considered SNR values), hence being suitable for intra DC connections. Longer connections may be achieved, reaching inter DC lengths, by utilising dispersion mitigation techniques. However, that study is out of the scope of this work.

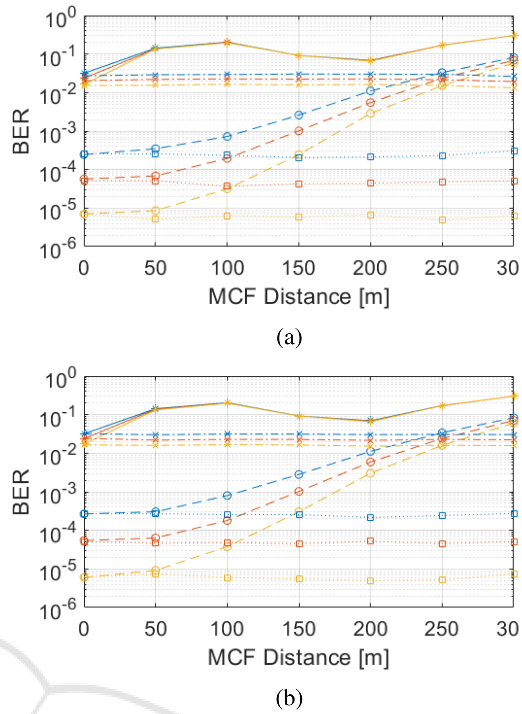


Figure 9: BER as a function of the MCF length, before SSBI removal with dispersion (continuous line) and without dispersion (dashed and dotted line), and after SSBI removal with dispersion (dashed line) and without dispersion (dotted line), for a laser linewidth of: (a) 100 kHz and (b) 5 MHz.

5 CONCLUSIONS

An innovative transmission scheme has been proposed, where the 200 Gb/s NRZ signal and the virtual carrier are transmitted in separate cores of a MCF, targeting a low complexity SSBI mitigation approach at the RX side to improve the system performance of short-reach MCF-based networks employing DD receivers. It has been shown that the combined effect of the skew and the laser phase noise affects the signal quality. Systems employing lasers with higher linewidths become more sensitive to the skew, limiting further the system performance due to phase-to-intensity conversion. It has been also shown that the proposed SSBI mitigation technique is effective only when a high P_r is considered, and for a low electrical noise environment.

For systems not impaired by the dispersion, a BER improvement (to values lower than 10^{-3}) after SSBI removal is obtained, for a P_r of 18 dB and a skew of 1 ns, and for a laser linewidth up to 5 MHz. Also, a BER lower than 10^{-3} is achieved for a skew up to 15 ns and a laser linewidth of 1 MHz. It has been shown that the dispersion rapidly degrades the received signal quality, exceeding a BER of 10^{-3} for a MCF length longer than approximately 180 m. The results indicate that, in absence of dispersion compensation, the proposed transmission scheme show potential to be employed in intra DC connections. Nevertheless, the higher potential of the proposed transmission technique is achieved for systems in which the dispersion effect is compensated electronically at the RX side. For systems with full dispersion compensations, the results show a significant performance improvement achieved by the SSBI mitigation approach employed, showing great interest for high capacity short-reach SDM networks.

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