Impact of Laser Impairments on DSCM-Based 800G Point-to-MultiPoint Coherent Transmission Systems

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Abstract: We experimentally investigate the impact of laser frequency linewidth and jitter on the design of uplink point-to-multipoint 800G DSCM systems. The performance degradation due to sub-band overlap, bandwidth limitation and DSP penalty is quantified.

1. Introduction

Digital subcarrier multiplexing (DSCM) has now been adopted widely in the industry for the future generation of 800G (long haul) transmission systems [1]. Its performance benefit over traditional single carrier transmission has been under debate in the research community but gain can be observed at least in specific scenarios (i.e. strong EEPN, colored noise channels...) [2, 3]. On the other hand, DSCM has been recently proposed to enable frequency division multiple access in point to multi-point (P2MP) aggregation network layer [4]. A Hub with 800G high speed transceiver is broadcasting to multiple users with net bit rate between 25G and 100G. In downlink, the Hub creates sub-bands of one or multiple subcarriers for each of the users and aggregates them digitally. On the user side, the local oscillator (LO) is locked on its sub-band center frequency and sub carriers (SC) are recovered through digital filtering. In uplink, every user transmit on their respective sub-band (using the same laser as for downlink), and the aggregation is realized in the optical domain by passive couplers. DSCM-based P2MP, offers greater flexibility than point-to-point for aggregation network, with a more efficient management of the user bandwidth allocation. It also results in cost reduction thanks to the passive optical aggregation that remove the need of opto-electronic conversion for network layer crossing [4]. While coupler based aggregation is very simple and cost effective, it gives no control on how sub-bands are combined and the proper realization of the aggregation relies on the tuning of the user lasers. Lasers have inherent frequency jittering that causes uncertainty on the center frequency of the transmitted sub-band. Sub-band from different users can thus overlap during the aggregation, causing inter-carrier interference (ICI). Sub-band effective spacing must be increased in order to avoid ICI. It can be done, by either inserting guardband or using wider pulse shaping (larger roll-off factors). However, this also increases the signal overall bandwidth occupation and results in filtering penalties.

The choice of the laser plays an important role in the design of P2MP. While the laser linewidth impacts the DSP performance (as in point-to-point), the frequency stability dictates the frequency spacing between the users and the overall bandwidth occupation. In this paper, using a two-users uplink experimental setup, we investigate the contribution of all the different effects that comes to play.

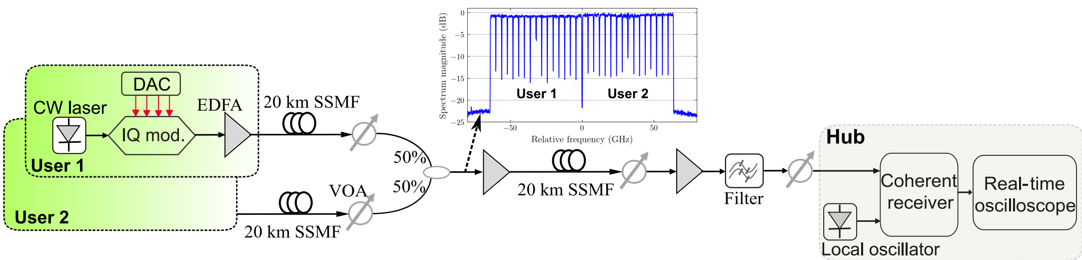

Fig. 1: Experiemental setup of a two-user P2MP uplink transmission

2. Experimental setup

The experimental setup of a two-user uplink P2MP is presented in Fig. 1. Targeting to 800Gb/s net capacity, each user transmits a sub-band of 16 subcarriers (3.75 Gbaud per subcarrier modulated with 16QAM signals

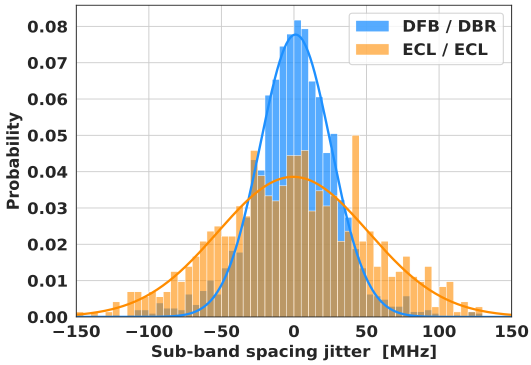

Fig. 2: Distribution of the sub-band spacing jitter for different user laser configurations

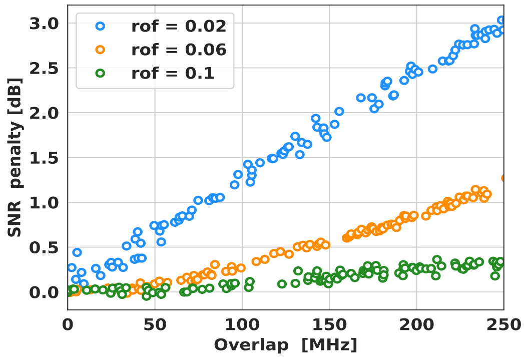

Fig. 3: SNR penalty in function of the overlap for 3.75 Gbaud subcarrier and OSNR = 28dB

corresponding to 25 Gb/s net capacity), with in total 32 subcarriers and 120 Gbaud cumulated baud rate. At the transmitter side, two continuous wave (CW) lasers serve as optical carriers for two users and are aligned in frequency so that the spectra of each user is put one next to the other. In each transmitter, the dual-polarization 16QAM 16-DSCM signals are generated from digital-to-analog converters (DAC) and modulated onto the optical carrier using an DP-IQ modulator. The output signal is then amplified by an Erbium doped fiber amplifier (EDFA) to compensate for the insertion loss of the modulator. After that, each transmitted signal is launched into 20 km standard single mode fiber (SSMF), before being combined together by an optical coupler. The signal level of each transmitted signal is adjusted by a variable optical attenuator (VOA), so that overall spectra is relatively flat (as indicated in the inset of Fig. 1). The combined signals are amplified and then sent over 20 km SSMF before reaching the receiver side. The received optical signal-to-noise ratio (OSNR) is varied by means of a VOA, cascaded to an EDFA and followed by an optical bandpass filter. Finally at the Hub side, the received signal is mixed with a local oscillator laser in a coherent receiver. It is then photodetected before being sampled by a 256 GS/s real time oscilloscop and fed to the digital signal processing (DSP).

3. Laser frequency jitter impairments

In order to characterize experimentally the effect of the laser jitter on the position of the sub-bands, acquisitions at high OSNR are taken over a large period of time and with different configuration of user lasers. Note that the frequency jitter of the Hub LO makes the two sub-bands move in the same manner so doesn't cause overlap. For each acquisition, the frequency position of each sub-band is estimated in the DSP by the carrier frequency estimation (CFE) block. The CFE accuracy is better than 5 MHz at this level of OSNR. The distribution of the spacing jitter between the two sub-bands is presented in Fig. 2. It represents the variation of the relative position of one sub-band compare to the other. The first case of interest is when users have distributed Bragg reflector (DBR) and distributed feedback (DFB) laser. These lasers have limited frequency jitter and the sub-band spacing presents little variation (variance of about 20 MHz). The second test case is when both users use external cavity lasers (ECL). ECL has built-in oscillator dithering that results in larger position jittering between the sub-bands (50 MHz variance). Maximum jitter can be up to 50 MHz with DFB or DBR lasers and more than 100 MHz with ECLs. If the spacing between the sub-bands is less than that, overlap and thus ICI will occur. We quantify this impairment experimentally by tuning the laser frequency of one user compare to the other and by measuring the performance of the overlapping subcarriers. The laser frequency varies by step of 100 MHz (plus or minus the jitter). Figure 3 shows the side subcarrier SNR penalty as a function of the sub-band overlap for different roll-off (ROF). Subcarriers with low roll-off factors are very sensitive to the overlap. The case with a 0.02 ROF presents more than 1 dB penalty with 100 MHz overlapping. Increasing the roll-off improves the tolerance to overlapping. A subcarrier with 0.06 ROF has 0.2 dB penalty at 100 MHz. Inserting guarband is another solution to increase the spacing between sub-bands. It would be similar to translating the curves to the right in Fig. 3.

In our setup with 32 x 25Gb/s subcarriers, the bandwidth occupation goes from 122 to 132 Gbaud for ROF between 0.02 and 0.1. In the latter case, significant filtering effects occur on the side of the spectrum due to the bandwidth limitation of the photodiodes (about 65GHz). This reduces the overall net capacity of the uplink transmission as shown in Fig. 4. Instead of increasing the roll-off or guardband, another solution is to sacrifice the P2MP flexibility and support less number of users and use higher rate subcarrier. In Fig. 5, we show that using 7.5Gbaud SC (16x50Gb/s) or 15Gbaud SC (8x100Gb/s), the impact of ICI due to jitter stays low.

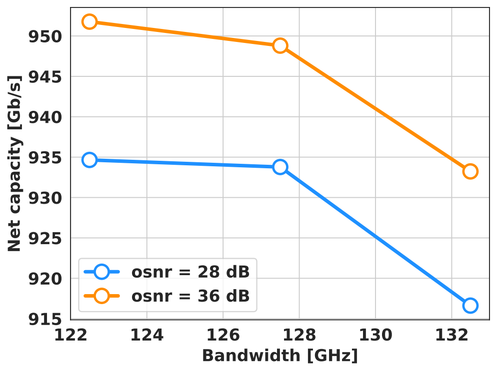

Fig. 4: Net capacity (from measured GMI) as a function of the bandwidth occupation (caused by increasing ROF)

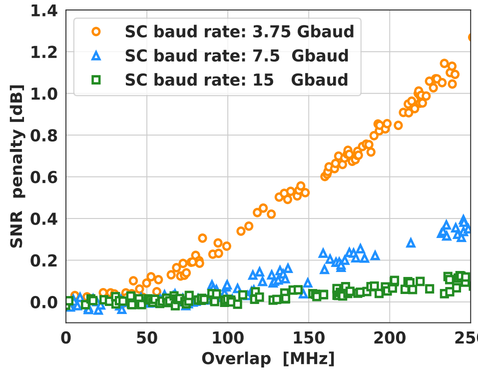

Fig. 5: SNR penalty in function of the overlap for different SC baud rate and roll-off = 0.06, and OSNR = 28dB

4. Laser linewidth impairments

Apart from the frequency jittering, laser linewidth is another relevant factor in P2MP. For good flexibility, the system should be based on low baud rate subcarriers for example 32 x 3.75 Gb/s, which makes DSP very sensitive to laser linewidth. Figure 6 presents the penalty of realistic carrier phase recovery (CPR) compared to the ideal data-aided CPR, for different user/Hub laser configurations. The number of averaging taps is optimized for each case. The use of ECL lasers and 2-stage CPR (pilot aided + maximum likelihood(ML)) helps maintaining DSP performance reasonable. ECLs are more expensive than DBRs and for cost reasons, may not be available. An alternative for better tolerance to linewidth would be to increase the SC rate (thus reducing the number of users) as shown in Fig.7.

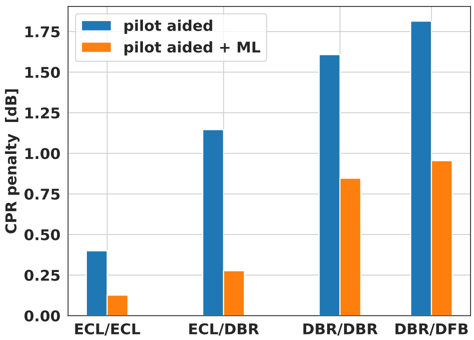

Fig. 6: SNR penalty of CPR algorithms compared to data-aided CPR for different user/Hub lasers, measured at OSNR = 28dB

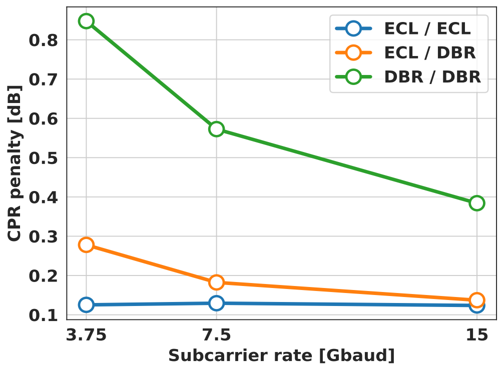

Fig. 7: SNR penalty of 2-stage CPR compared to data-aided CPR for different SC baud rate, measured at OSNR = 28dB

5. Conclusion

Lasers are key components and their linewidth and frequency stability properties have a strong impact on DSCM-based P2MP system performance. While these impairments can be partially mitigated with robust DSP and larger bandwidth occupation respectively, having good lasers remains necessary in order to support a large number of low rate SC. If having such good lasers is not an option due to cost or power budget constraint, using larger rate SC and lower number of supported users can be considered but this decreases the flexibility and thus, one of the main advantage of DSCM-based P2MP systems.

References

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