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High-Speed Optical Transmission with Coherent Detection Based on DSPs

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Abstract: The recently reported the high spectral efficiency and high-baud-rate signal transmission are all based on digital signal processing (DSP). DSP simplifies the reception of advance modulation format and also enable the major electrical and optical impairments to be processed and compensated in the digital domain, at the receiver or transmitter side. In this paper we summarize the research progress on high speed signal detection.

Keywords: DSP, FDM, Coherent system, SDM, Optical communication, Advanced DSP.

I. INTRODUCTION

The rapidly increasing data traffic nowadays has aroused urgent demands for higher spectral efficiency (SE), higher speed and higher capacity in optical communication systems. To further improve the transmission speed and system capacity, researcher has proposed approaches concerning multi-level modulation formats and various multiplexing technique, including frequency-division multiplexing (FDM), Time- division multiplexing (TDM), polarization- division multiplexing (PDM) and Spatial-division-multiplexing (SDM) . Recently 100G based on coherent detection is being widely deployed. 400G or 1T per channel on a single optical carrier is an attractive solution in future network, since it reduce the complexity and cost of transmitter and receiver, pushing the boundaries of opto-electronic devices and modules. Two viable option for high baud rate signal generation are always considered, one is based on FDM and the other on TDM. To generate the high -baud-rate signals, a multiple spectral slices synthesis multiplexing technique is also recently proposed based on transmitter side digital signal processing (DSP).TDM is another effective method for high- baud-rate signal generation , it can be divided into two major categories, Electrical-TDM (ETDM) and all-optical TDM(all-OTDM). Single-Wavelength all-ETDM 107-GBaud and 110-GBaud signals are successfully generated and transmitted as the highest ETDM baud rates.

DSP Based coherent optical system has become one of the most active research topics, and it is a promising technology for future high SE and high speed transmission. on the other hand , multiplexing techniques including wavelength division multiplexing (WDM), PDM, TDM, and Spatial division multiplexing (SDM) methods, such as Mode Division Multiplexing (MDM), Multi –core fiber multiplexing and Laguerre-Gaussian (LG) beam carrying orbital angular momentum (OAM) modes, are also considered as promising solution to improve the capacity and SE further.

II. HIGH SPEED SIGNAL GENERATION AND DETECTION

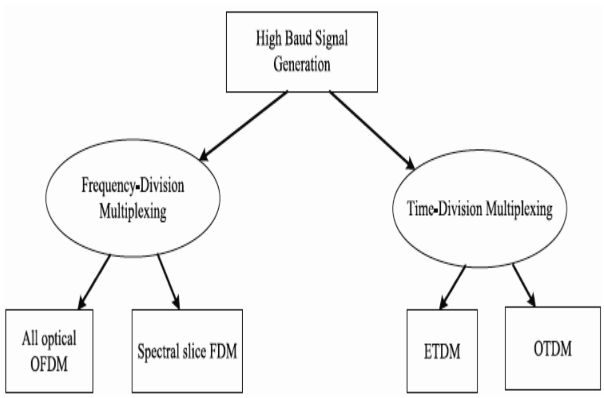

Fig.1 : High baud rate signal generation by FDM and TDM methods reported in previous work

Figure 1 shows two option one is based on TDM and other is based on FDM. The FDM method includes the recently reported all –optical OFDM and multiple spectral slices synthesis multiplexing technique.TDM is another effective method for high- baud -rate signal generation based on the ETDM or all OTDM. In this sect-ion, we will present the recent progress on high-baud-rate signal generation based on ETDM and OTDM methods.

Fig.2Shows the experimental setup of the 20-channel, 100GHz-grid, 440-Gb/s single-carrier super Nyquist filtering 9-QAM-like signal generation and transmission based on a 110-GBaud PDM-QPSK.

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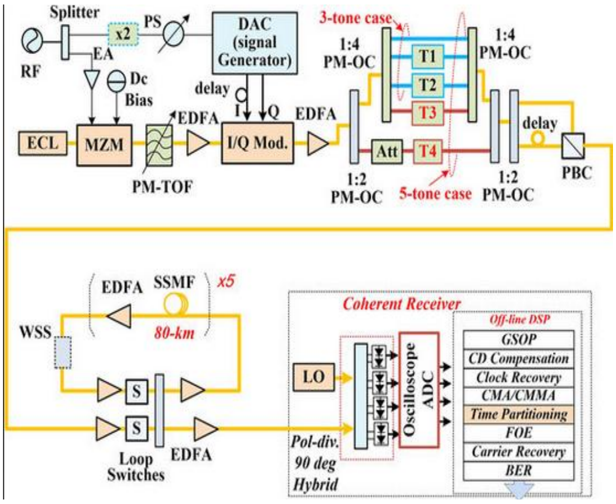

Fig 2: 110 GBaud QPSK signal generation, transmisson and coherent detection system.

At the coherent receiver, full baand coherent detection is realized by one free-running CW LO working at central frequency of the comb, and it is simpler compared with the typicalOTDM receiver .

III. ADVANCED DSP

As we mentioned above, the high SE and high baud rate signal processing requires an advanced DSP. In this section we present the recent progress in DSPs in digital coherent system. Fig.3 shows the typical digital coherent receiver with a DSP for signal equalization and recovery

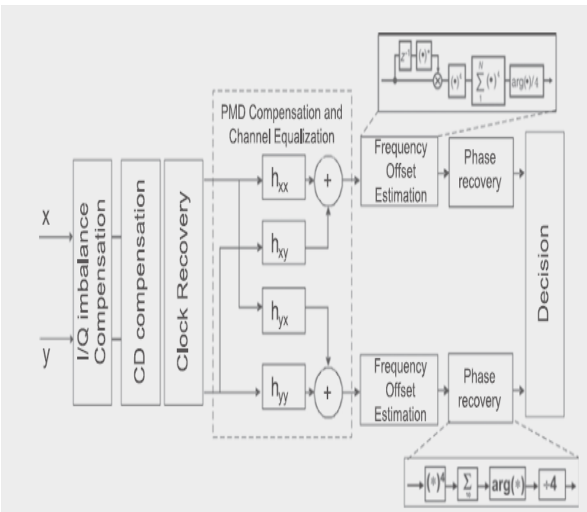

Fig.3: Typical digital signal processing at-the receiver side for coherent optical communication.

Figure 4 shows the simulation Result of 32Gbaud signals (QPSK 8QAM and 16qam) after 1000km transmission with basic DSP sub-units. Based on the DPS sub-units, we observe the constellation recovery process after all these algorithms. In the aforementioned simulation demonstration the QPSK signals are processed based on CM A equalization, while 8QAM and 16QAM are based on CMMA and DD-LMS. For FOE and phase recovery QPSK signal is processed by 4th power Viterbi-Viterbi algorithm, while 8QAM and 16QAM are processed by frequency-domain FOE and BPS method.

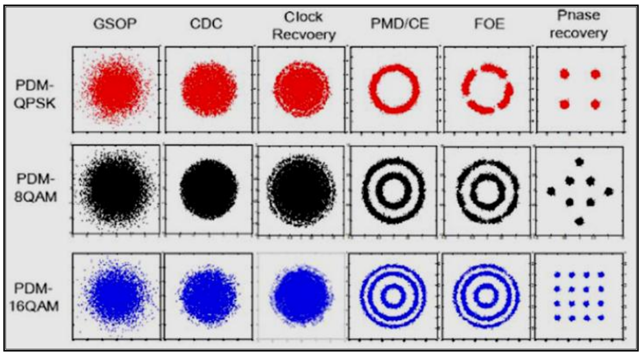

Fig4: The constellation of different signals after 1000-km transmission with DSP

Recently, Non linear compensation (NLC) by using DSPs has become an attractive research topic, especially for long –haul high speed coherent transmission system. The digital backward propagation (DBP) method has been theoretically and experimentally investigated by using an improved NLSE for single channel PDM systems in previous works. it has demonstrated that DBP, based on the split-step fourier method (SSFM),is an effective way to compensate for the nonlinear effect, such as self-phase modulation(SPM),Cross-phase modulation and Four-wave mixing (FWM)

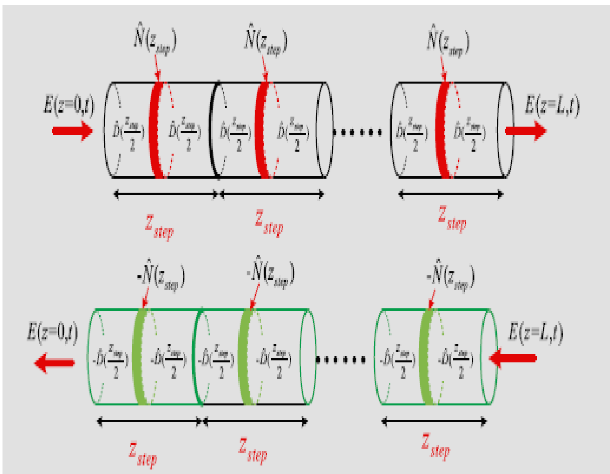

Fig5: The principle of the fiber nonlinear compensation based on digital backward propagation (DBP) method.

In addition, pre-compensation or pre-equalizations based on the DSP at the transmitter side (Tx) further improves the system performances.

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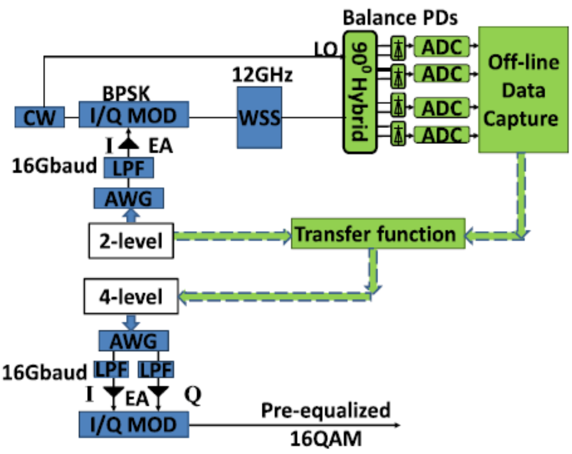

Fig6: The principle of pre- equalization.

IV. SPATIAL DIVISION MULTIPLEXING (SDM) MULTIPLEXING

The rapidly increasing data traffic nowadays has aroused urgent demand for higher spectrum efficiency and higher capacity in optical communication systems. To further improve the system capacity, researches have proposed approaches concerning multilevel modulation formats and various multiplexing techniques. Expect for those who widely use multiplexing techniques, including WDM, PDM, TDM and other SDM methods, such as MDM, multi core fiber multiplexing and Laguerr-Gaussian (LG) beam carrying OAM modes, are also considered as promising solutions. To further improve the capacity and spectral efficiency.

The property of OAM carried by a LG beam was studied by allen and then introduced to free-space optical communication (FSO). Since OAM has an infinite number of orthogonal eigenstates. it can be utilized as an additional degree of freedom (DOF) for modulation or multiplexing . OAM multiplexing provides improved system capacity and spectral efficiency of optical system.

The LG beam carrying OAM mode features a helical face front, which can be described by an azimuthal phase term exp(ilϕ). The value l is known as the topological charge which stands for different orthogonal eigenstates corresponding to different modes and ϕ is the azimuthal phase. OAM is lh per photon where l must be an integer(l=0,±1,±2..). By employing reflective spatial light modulator (SLM) with pre-calculated hologram Pattern, the signal can be converted onto a specific OAM mode to realize multiplexing or be converted back to the fundamental Gaussian Beam(l=0) to realize demultiplexing . we use hologram pattern shown in fig 7(a) and (b) to generate and demultiplex the two OAM modes. It is worth noting that the mirror image relation -ship was introduced by reflection results in the apposite signs between the charge applied to SLM and charge of OAM actually converted.

Due to the physical limits, i.e., the limitation of input optical power and the resulting OSNR reduction, fiber nonlinearities, Shannon limit and the bandwidth limit of the amplifiers, it is believed that the maximum capacity will be saturated at around 100Tbit/s. In order to further improve the capacity, SDM based on multi-core fibers (MCFs) is believed to be a promising technique for overcoming such limits in SMF. 305-Tb/s transmission over 10.1Kmusing a 19-core SDM Fiber based on 100-WDM PDM-QPSK Signals was demonstrated.

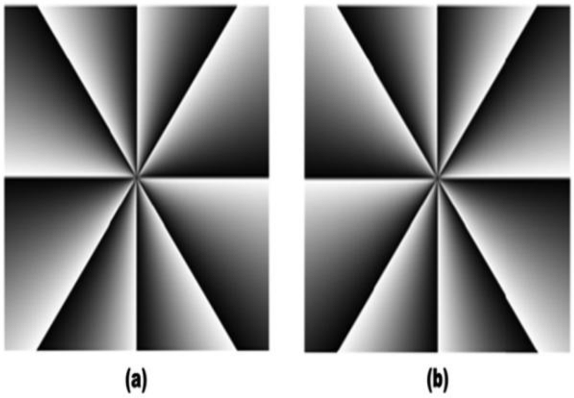

Fig7: SLM hologram pattern with charge of (a) +8 and (b) -8

V. HIGH-SYMBOL-RATE COHERENT SYSTEMS

Looking ahead of the landscape for DSP-based coherent optical communication, one of the possible bottlenecks for realizing future high-symbol-rate transmission systems is the ADC technology. Coherent optical time-domain sampling (COTDS) can be a potential solution, as it can be used to demultiplex the waveform into tributaries slow enough for electronic ADC. from one symbol are demultiplexed into two data streams at half the symbol rate.

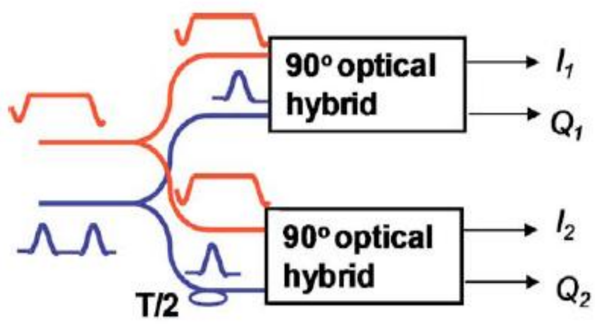

Fig8. Schematic

A 1_2 COTDS experiment was carried out to demonstrate 10 G bit/ s BPSK transmission and dispersion compensation. The setup is shown in Fig.9.

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A 10 Gbit/ s BPSK signal after 220 km standard single-mode fiber (SSMF) [D=17 ps/ _km nm_] transmission was coherently detected by using COTDS, and the dispersion was electronically compensated. For dispersion compensation, a sampling rate of 20 Gsamples/ s is required for 10 Gbit/ s signal. In this experiment, the sampling rate ADC was set at 10 Gsamples/ s, and two COTDS pulse trains with repetition rate of 10 GHz were used as LOs to perform parallel optical sampling.

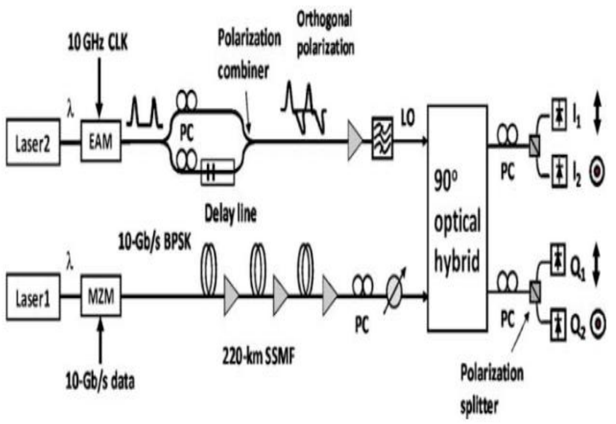

Fig9. Experimental setup for COTDS

The wavelengths of the transmitter and the LO laser were 1550 nm, and their frequency difference was tuned to be as small as possible. An electro absorption modulator was modulated by a 10 GHz clock at a proper bias point to achieve a pulse train with a pulse width around 20 ps. The pulse train was then divided into two by a 50 ps relative delay.

Polarization manipulations were used so that only one 90° optical hybrid is required, and the two orthogonal LO pulse trains beat with the received signal independently. The outputs of the hybrid were separated by two polarization splitters and then detected by four detectors with a 12 GHz bandwidth. A real-time digital oscilloscope was used as ADC and sampled at 10 Gsamples/ s. The signal power launched into SSMF was 0 dBm, and the EDFAs had noise figures around 5 dB. The total LO power was set to be −2.6 dBm.

VI. CONCLUSIONS

We have reviewed the recent progress on high-speed optical transmission with coherent detection based on DSPs. The trend for bit rate per channel is form 100G to 400G and even higher. 100G per channel is widely deployed, and 400Gfor 1T is a hot research topic. Using advanced DSPs can greatly improve the signal performance and spectral efficiency, and reduce that time consumption for signal procession. Using multi-core and multi-level multiplexing Technologies can greatly increase the capacity.

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