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Transmission of SDM/DWDM System over 1500-KM with 16 Spatial and Polarized Modes over Few-Mode Fiber Enabling Advanced DSP Algorithms

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***Abstract* - The paper demonstrates simulation framework for few-mode fiber based space division multiplexing (SDM) transmission system. The technique has been proposed as an option for further capacity increase of transmission fibers. In this paper the space division multiplexing (SDM) is used to obtain ultra-high data rate. Polarization dual multiplexing (PDM) and dense wavelength multiplexing (DWDM) techniques are also used in this system to increase total system data rate. The proposed system is tested under different baud rates and QAM modulation formats.**

Keywords: Few-Mode Fiber, SDM, Transmission System, PDM, DWDM, QAM.

I. INTRODUCTION

With the noticed increase in Internet traffic, demand for much higher capacity will increase in optical communication networks to accommodate future high definition videos and new data communication services. The main goals in developing new wireless communication systems are increasing the transmission capacity and improving the spectrum efficiency [1]. Single-mode fiber (SMF) has been the best medium for high-capacity data transmission for over three decades. However, the exponential growth of internet traffic at about 2 dB per annum could exhaust the available capacity of SMF in the near future (2). An important area of applications, driving the research that has led to many of the advances in photonics in the last thirty years is optical communications (2). Space division multiplexing (SDM) in optical fiber link is expected to keep increasing the communication capacities besides the conventional multiplexing techniques (3). The fiber-based space division multiplexing(SDM) techniques include mode-division multiplexing (MDM) using few-mode fibers (FMFs) [4], spatial multiplexing using multi-core fibers (MCFs) [5] or using helical excitation of different spatial angles [6], and orbital angular momentum (OAM) multiplexing using special ring fibers[7]. These new multiplexing techniques have also been introduced to free space optical communications. Today's SDM research is also occurring as coherent detection and digital compensation are capable of overcoming complex impairments (such as polarization mode dispersion (PMD) and are accepted as a standard part of high- performance systems. This is crucial: since SDM packs spatial channels tightly into each fibre, crosstalk between channels is an obvious potential disadvantage and needs to be addressed. The addition of significant crosstalk to a transmission line would have been particularly unattractive a few years ago, before coherent-detection systems offered hope of subtracting out crosstalk electronically at the receiver [8]. These enabling technologies have made SDM a viable strategy just as a severe need for innovation emerges [8]. Over the past forty years, a series of technological breakthroughs have allowed the capacity-per-fibre to increase around 10x every four years. Transmission technology has therefore thus far been able to keep up with the relentless, exponential growth of capacity demand. The cost of transmitting exponentially more data was also manageable, in large part because more data was transmitted over the same fibre by upgrading equipment at the fibre ends. But in the coming decade or so, an increasing number of fibres in real networks will reach their capacity limit [9]. Keeping up with demand will therefore mean lighting new fibres and installing new cables - potentially also at an exponentially increasing rate. Further, this fibre capacity limit is not specific to a particular modulation format or transponder standard - it is fundamental and can be derived from a straightforward extension of the fundamental Shannon capacity limit to a nonlinear fibre channel under quite broad assumptions [10]. It says that standard single mode fibre (SMF) can carry no more than around 100Tbit/s of data, corresponding to filling the C and L amplification bands of the erbium doped fibre amplifier (EDFA) at a spectral efficiency of ~10 bits/s/Hz. The upcoming potential "capacity crunch", then, is an era of unfavorable cost scaling. For some carriers who have access to a limited number of dark fibres, very expensive installation of new cables will be the only alternative as the capacity of existing fibres is filled. "Fibre-rich" carriers who attempted to future-proof their fibre plant by including large numbers of premium fibres in each cable (thus putting off the need for

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subsequent new cables) will be forced to overbuild, i.e. deploy multiple systems over parallel fibres, to keep up with demand. However, multiple systems over parallel fibres suggest that transmission costs and power consumption will scale linearly with growing capacity. The anticipated promise of SDM is not only that it will provide the next leap in capacity-per-fibre but that this will concurrently enable large reductions in cost-per-bit and enhance energy efficiency [11]. This is a formidable challenge. SDM is very different from wavelength division multiplexing (WDM) which inherently allows the sharing of key components: e.g., an EDFA and dispersion compensation module can easily be shared by many WDM channels with minimal added complexity. The benefits of SDM are more speculative, and assume that many system components can be eventually integrated and engineered to support this potentially disruptive new platform. Given this emerging need, major research effort has been mobilized around the world to explore and establish the viability of SDM [12]. Exciting contemporary results show that a wide array of new tools are now being concentrated on investigated the possible benefits of SDM, and chipping away at the many engineering problems obscuring these benefits[8]. In this paper, we here focus on the SDM systems using FMF. In particular, we will elucidate the overall system architecture, components and system modules for MMF transmission.

II. SYSTEM DESCRIPSION

To increase the transmission reach of the optical signal and enhance the system performance, the system must be designed properly by accurate selection of the various components in the system. In this paper, we proposed DWDM/PDM/SDM transmission system. The signal is transmitted over 21 wavelengths (50GHz spacing) in 8 spatial dimensions (fiber cores). Each wavelength is modulated with different data rates and different modulation formats to achieve the best performance. The multicore fiber is emulated using few-mode fibers (FMF) with no distributed coupling between modes. EDFA module array used to gain control system. The system will be discussed under different data rates and bits per symbol QAM formats. Our framework includes the following sections:

a) DWDM combiner source:

First, The DWDM combiner source section includes the generation of 21 optical signals by using Laser CW module to model a DFB laser producing continuous wave (CW) optical signals. Then, the generated 21 wavelengths multiplexed by DWDM ideal Multiplexer. The output of multiplexer passes through power splitter to split the multiplexed 21signals equally into the special cores.

b) SDM system model:

The multiplexed optical signals will pass through 8 dimensions (fiber cores) .Arrayed waveguides (AWGs) used to do the multiplexing and demultiplexing in the fiber cores. Each wavelength is modulated at 30 &40Gbaud with a dual-polarization QAM formats.

The output of the cores travel into multi core fiber (MCF).The output of special cores interleaved into multi core fiber through bus creator 8*1. The length of multicore fiber is 1200 km.

c) Receiver section:

At the receiver, bus selector used to choose cores to be decoded. For example, for our system we select core (5) to be decoded and record the results. Optical filter module used to band passes each core with the standard Gaussian transfer function. The received polarized core Signals passes through polarization-diversity digital coherent. Matched filter used as finite impulse response to output the float numbers. Another DSP module does the Time domain equalizer and MIMO algorithms for the output float numbers. Then, we did phase_16QAM to achieve the Carrier Frequency and power Recovery (CFR) algorithms for received data. Synchronous DSP module used to recover the time offset of the sampled signals represented by a matrix by performing correlations between them and the reference regenerated from the data carried by our specified channels. The time offset is compensated by circularly shifting the sample arrays (matrix columns). The primary intended application of this module is to perform ideal synchronization for a sample of single received optical signal that has been divided into two or four signals, according to quadrature components and polarization.

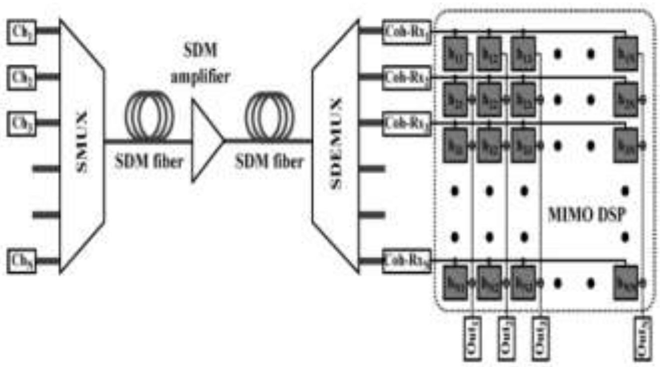

Figure-1: Schematic of a DWDM-SDM transmission system based on coherent MIMO-DSP

Find a sub-matrix of the input matrix done by sub-matrix module to show the required rows and columns to be tested in

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BER tester. Channel 11x recorded for each core to study the system behavior under different settings.

III. RESULTS AND DISCUSSION

We run the DWDM-PDM-SDM transmission system with different bit rates and then with different modulation formats and recorded the results to obtain the best performance for the system. First we run the system under baud rate of each signal 30Gbaud and then 40Gbaud used with 16QAM format and we recorded the total data rate: by assuming baud rate 30Gbaud and the bits per symbol set to (4) the total bit rate of system is 10.08 Tb/s (30G*2*21*8), while when baud rate is 40Gbaud then the total data rate is 13.44 Tb/s (40G*2*21*8). We surely found that the total system data rate is better for 40 Gbaud but the dispersion losses increased.

a) Dispersion compensation: We know that the performance of SDM transmission system is better in 30Gbaud than 40Gbaud because the chromatic dispersion losses increased as the baud rate increases. Dispersion Compensator applied with digital signal processing (DSP) module by receiving the input sampling rate and outputs the post-processing sampling rate as a float numbers. We testes core 5 for example and recorded the results, as shown in figures (2 and 3).

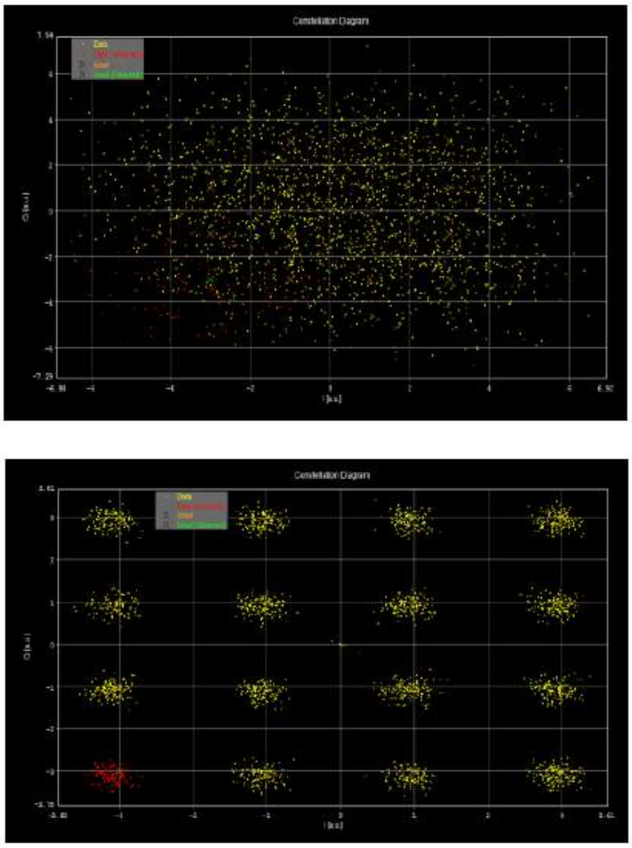

Figure-2: Received not equalized data (above) and received equalized data (bottom) for 40Gbaud in core 5

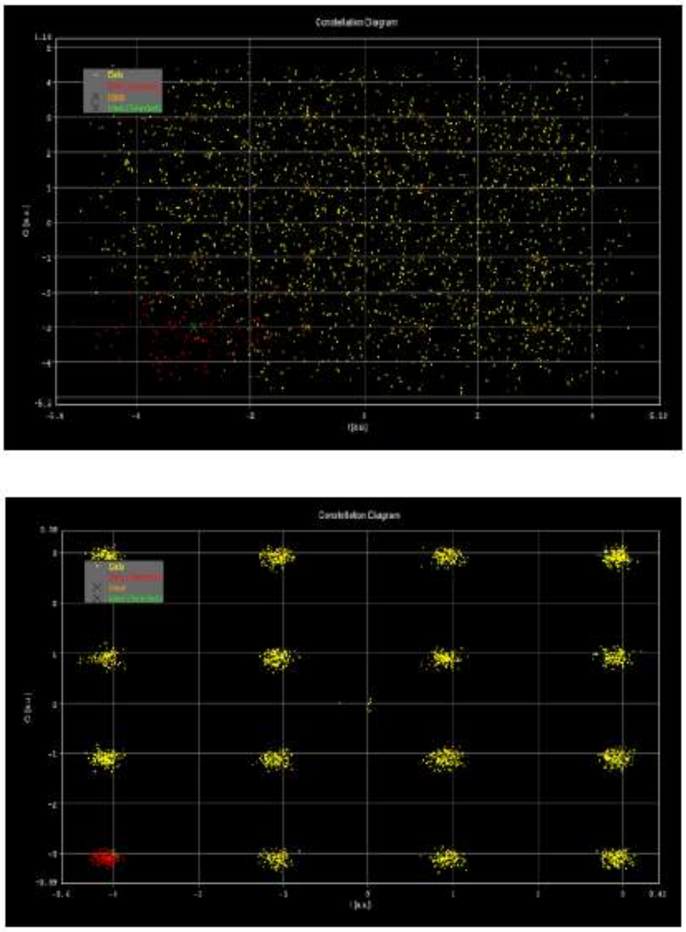

Figure-3: Received not equalized data (above) and received equalized data (bottom) for 30Gbaud in core 5

b) Quadrature Amplitude Modulation (QAM) Formats: To further enhance the capacity with adorable cost and complexity, on each wavelength is suggested to be modulated with QAM advance modulation format. The advantage of using QAM is that it is a higher order form of modulation and as a result it is able to carry more bits of information per symbol. Our system tested with constant baud rate of 40Gbaud and different bits per symbol values to achieve the best required modulation format that produce the best system performance, as follows:

4QAM: In this modulation format the number of bit per symbol is (2) bits per symbol producing a constellation diagram of four bits. We saw that the performance of system is high and the cross talk losses are low as compared with 16QAM format, as shown in figure 4.

16QAM: This modulation format achieving (4) bits per symbol producing a constellation diagram of 16 bits, as shown in fig. (5). the data rate of system is increased and the transfer of data is faster. While higher order modulation rates are able to produce much faster data rates and higher levels of spectral

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efficiency for the radio communications system, we found that the higher order modulation schemes are extremely less resilient to noise and interference. So for higher and faster data rate 16QAM format is favorable, but for better system performance in presence of cross talk 4QAM format is appropriated.

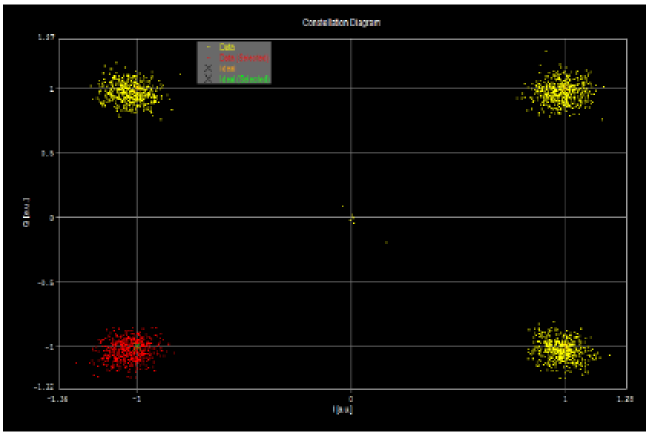

Figure-4: Constellation diagram of SDM system received data under 4QAM format

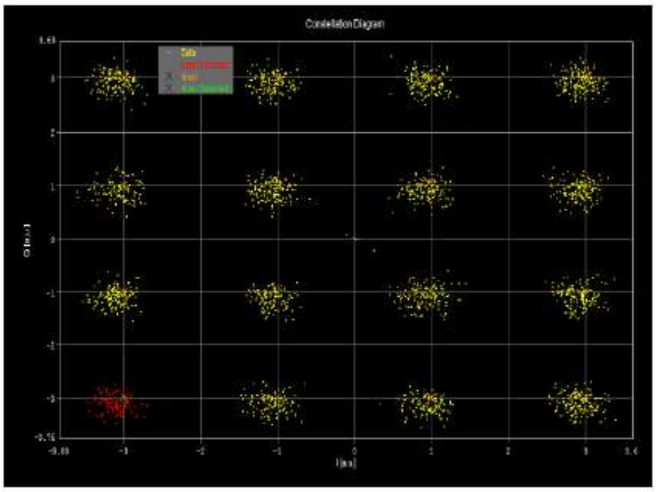

Figure-5: Constellation diagram of SDM system received data under 16QAM format

VI. CONCLUSION

In this paper we described a DWDM/PDM/SDM optical transmission system which can be expected to be applied for high data rate system. The proposed system is flexible in terms of assigning more high data rate systems. Simulation results demonstrate that the proposed scheme can support high bit rate system and better BER performance with increased data rate. Further, it has to be noted that the performance of system can be improved employing different technologies.

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