DIRECTIONLESS MULTI-CORE FIBRE LINKS USING PROGRAMMABLE ARCHITECTURE ON DEMAND OPTICAL NODES

Muhammad Irfan Anis
High-Performance Research Group, FEST, Iqra University Defence View, Karachi, Pakistan
mirfananis@iqra.edu.pk

ABSTRACT— *The main engine for allowing elastic optical networks is SDM transmission technology. In this context, the design of an SDM-based network with applicability to datacenter networks has become very difficult since it must overcome the capacity restriction of a fiber connection. In this work, we show the first SDM multi-dimensional and directionless switching that provisions the transmission of legacy lower bitrate and future high-speed super-channels in traditional single-core and two 7-core multi-core fibers using programmable Architecture on-demand optical nodes. The results indicate that all channels performed flawlessly, with a maximum power penalty of 2.5 dB.*

Keywords— Architecture on Demand, Datacentre, Elastic optical network, multi-core fiber, Space Division Multiplexing

I. INTRODUCTION

New fiber-based broadband services need large-scale computing platforms like datacenters, thus backbone networks need to be upgraded urgently [1]. Moreover, future optical networks' bandwidth requirements vary greatly in size [2]. Examples of high-bitrate traffic (TB/s) needed for datacenter connection include high-bandwidth (100 Mb/s) and low-bandwidth (Gb/s) requirements. Future network evolution will likely expand this range of traffic granularities beyond 100G [3]. In high-capacity super-channels, temporal division multiplexing (TDM), polarization division multiplexing (PDM), wavelength division multiplexing (WDM), multi-level signaling, and forward error correction (FEC) have been shown to achieve tens of Tb/s [4-6]. Fiber nonlinearity [8,] launching power limitation due to fiber fuse and limited bandwidth of fiber amplifiers [9] have recently been shown for conventional single core fiber. One data stream may not be enough to meet future demands. Data mobility at Peta scale through multi-core/multimode fibers, as well as trans capacity scalability, are all advantages of new technology for the aforementioned data services stated. Spatial channel expansion using multi-core fiber (MCF) over a space division multiplexing (SDM) [10]. SDM transmission technique has been extensively studied [11-12]. The number of spatial channels per fiber must be raised to properly use this technology in optical networking. So that highly used network locations, such as data centers, may seamlessly interoperate with areas using conventional Single Mode Fiber (SMF) lines, should be possible. The lack of research on SDM-capable elastic nodes is another issue. Efficient ElasticSDM with a multi-granular network capable of switching traffic with over 6000-fold bandwidth granularity [13]. To allow high bandwidth flexibility and mixed traffic, this study examines for the first time the results of optical SDM multi-dimensional networking. 2x7 MCFs were shown using 4xprogrammable Architecture on Demand (AoD) all-optical nodes on a single core fiber. Wire-speed 1.8-Tb/s traffic transmission across 555Gb/s, 23x42.7Gb/s, and 27x10Gb/s channels was successfully demonstrated.

The paper is organized as follows. SDM-based directionless switching in MCF is described in Section II, and the experimental investigation of novel networking architecture is presented in Section 3. We report our network testbed findings on a real-world deployment scenario in Section 4. A discussion of future studies on the topic concludes the essay.

II. DIRECTIONLESS SDM SWITCHING

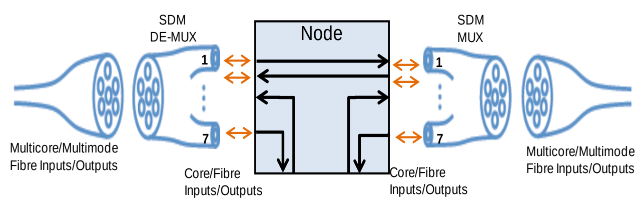


Fig. 1 Proposed directionless traffic implementation in SDM network

To use SDM technology in optical networks, small optical nodes must be able to switch large amounts of data while also switching at coarse granularities (core-to-fiber, core-to-core, fibre-to-core). An elastic optical node architecture that can expand to accommodate SDM technology while still offering directionless services is illustrated in Fig.1. This topology also enables a band to be routed to any degree of the architecture on the demand node. However, using SDM transmission technology, a broad range of all-optical granularities is possible. In the space domain, cores/fiber-containing signals are switched without De (Mux), resulting in improved node scalability. High scalability is achieved on optical backplane cross-connect, used to switch high volumes of data at the coarsest granularity, i.e., core/fiber switching. On the other hand, switching core/fiber necessitates that all input signals be routed to the same output. On the off chance that not, core/fiber may have to be demultiplexed e.g. using Spectrum Selective Switch (SSS) used for girdles/flex grid switching into distinct channels/bands before being combined at the destination An Architecture on Demand (AoD) node provides multi granular support, substantial scalability gains, allows for irrational switching granularities on any port, includes high-port count optical backplane 3D Micro-electromechanical switch for time based subwavelength switching [15], various plugin units e.g. SOA-MZI provide optical signal processing capabilities such as format conversion, multicasting, wavelength conversion, segment defragmentation [16], Lead Lanthanum Zirconate Titanate switches [17], optical amplifier(SOA, EDFA), etc. Large amounts of data may be switched across single backplane cross-connections thanks to coarse-grained traffic switching (fiber/core switching).

III. EXPERIMENTAL SDM NETWORK SETUP

4 programmable optical nodes with variable capacity/capabilities make up the flexible multi-dimensional switching network. Fig. 2 shows Node 2 acts as an optical backplane for SMF/MCF input and output connection. 7 core fiber MCF-1 had the core-loss fluctuation of 0.4dB over 11 hours and 3km single step-index homogeneous 7 core fiber MCF-2 had the core-loss fluctuation of 0.2dB having an average cross-talk of -56.5 dB and -53.8 dB, respectively are used to connect nodes 1-3. Both MCFs were made by Mitsubishi Cable Industries and lost 2 dB and 2.4 dB respectively while using SDM MUX/DEMUX devices 90[19].

Nodes 1, 3, and 4 each have their own 160x160 3DMEMS switch with a switching time of 20ms. Node-2 [20] is a 16x16 beam steering switch. Average cross-connection loss are 2 dB and 0.59 dB for each switch. SMFs of various lengths link Node-4 to Nodes 1, 2, and 3. A semiconductor MLL produces a 2-ps pulse train at a 10.675 GHz repetition rate and -6 dBm power for 555Gb/s generation. A High Non-Linear Fiber with a nonlinear coefficient of 10.1/W.km, Aeff = 10.3m, 1550nm zero-dispersion wavelength, and a dispersion slope of 0.03ps/nm/km is fed this signal. Here SPM broadens the signal's spectrum and shortens the pulse length due to the fiber nonlinearity. Following this, a 4.5-nm top bandpass filter selects 52 frequency components with a 3 dB peak-to-peak power difference. The signal is subsequently dispersed through a dispersive medium to convert frequency time. The signal's frequency components shift in and out of phase

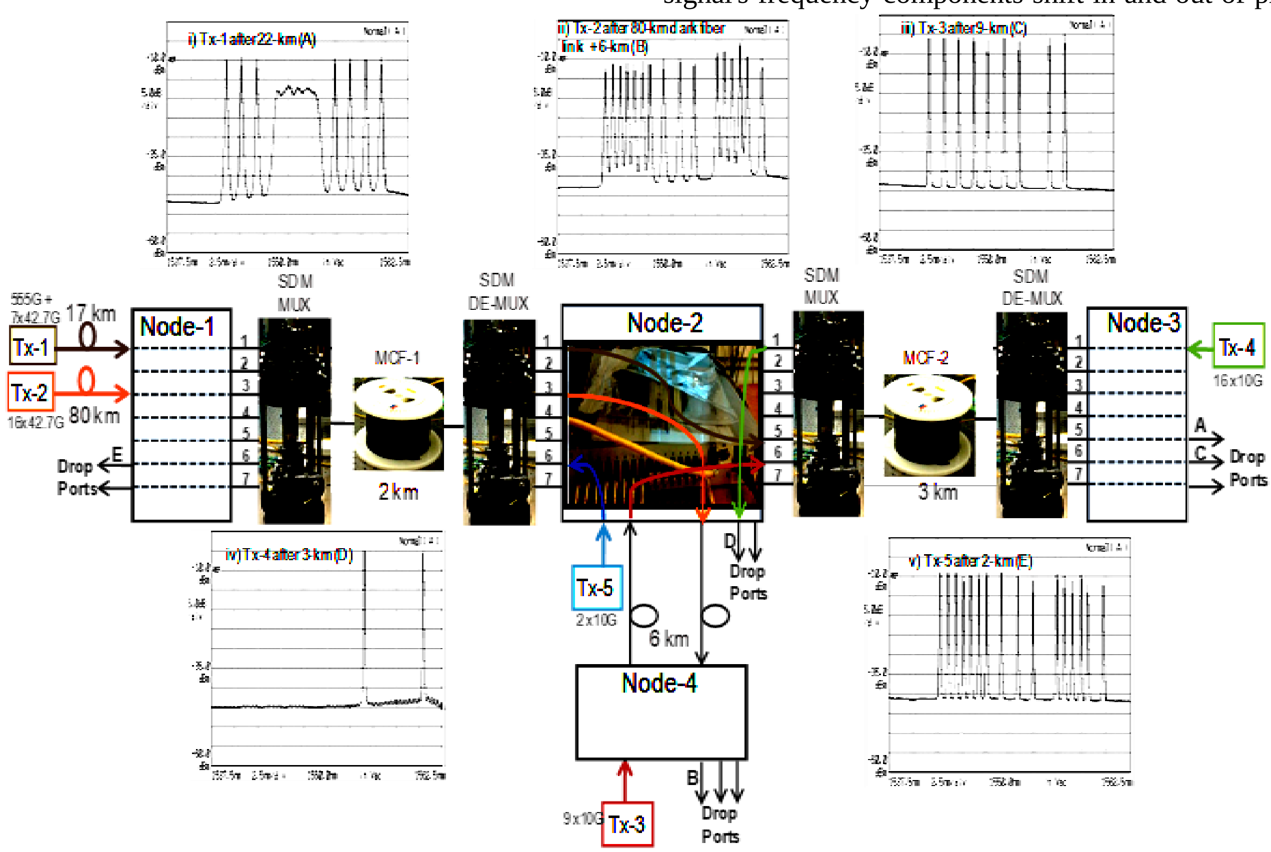


Fig. 2 Experimental network configuration and optical spectrum plot

as they travel through the dispersive medium, resulting in smaller pulses at lengths and time intervals where they interact constructively. A single pulse at the dispersive medium's input becomes four pulses across 16.7 kilometers, quadrupling the pulse rate. The experiment utilized a 16.7 km long SSMF to introduce 274.23 ps/nm, resulting in a 23.4-ps delay between subcarriers. The duration between successive pulses is now 23.4 ps instead of 93.67 ps. It is then IM in a LiNbO3 MZM by 4 electrically multiplexed PRBS of length 27-1, 29-1, 210-1, and 211-1 at 10.675Gb/s each. As a consequence, each adjacent subcarrier has its own PRBS. Tx1–Tx5 use LiNbO3 MZM to generate 42.7Gb/s and 10.675Gb/s OOK signals.

Input signals for nodes 1-4 (F-J) include 555 Gb/s, 42.7Gb/s, and 10.675Gb/s OOK NRZ traffic with varying destinations. Table 1 shows the constructed signals, their features, paths, and channel bandwidth allotment. In Fig. 2, various transmitters have varying lengths of signal transmission fibers. They are then transmitted over 17 kilometers of SMF to core 1 of MCF-1 where they are instantly switched to core 5 of MCF-2 to Node 3, bringing the maximum data rate of a space switched core to 853.9 Gb/s. Tx-2 channels 16x42.7Gb/s OOK NRZ are transmitted at Node-1 and forwarded to input G through an 80 km installed fiber connection between Colchester and Ipswich. The G signal is delivered to MCF-1 core 3, which switches it from Node 2 to Node 4. Due to the nature of switching at fiber/core granularities, space defragmentation is required. Tx-4's 2x10 Gb/s OOK NRZ (SMF) inputs are flexibly connected to MCF-2 core 1 in Node 3. In the case of a failure, they are discarded at Node-2 and forwarded to the In Node-2, the most granular toggling between dimensions is exhibited. Similarly, Tx-3 9x10 Gb/s OOK NRZ and Tx-5 9x10 Gb/s OOK NRZ input H and J signals are spectra swapped to Node 2, while MCF-1 core 6 goes to Node 1 and MCF-2 core 6 goes to Node 3. The network's directionless optical channels are shown in Fig. 2. The spectra of connections inset I after 22 km, inset II after 86 km, and inset III after 9 km correspond to transmission from west to east, whereas links inset IV and V after 3 km and 2km correspond to transmission in the other direction.

Table 1: Summary of the traffic used in the Directionless SDM Experimentation

Tx	Channels	λ[nm]	Channel BW [GHz]	Bitrate [Gb/s]	Source	Destination	Path
Tx-1	λ_0	1550.92	600	555	Node-1	Node-3	Node1-MCF1(core1)-Node2-MCF2(core5)-Node3
	λ_1-λ_7	1543.73-1559.79	100	7x42.7			
Tx-2	λ_8-λ_{23}	1542.94-1559.79	100	16x42.7	Node-1	Node-4	Node1-MCF1(core1)-Node2-Node4
Tx-3	λ_{24}-λ_{32}	1542.94-1557.36	50	9x10	Node-4	Node-1	Node4-Node2-MCF1(core6)-Node1
Tx-4	λ_{33}-λ_{34}	1554.13-1560.61	50	2x10	Node-3	Node-3	Node3-MCF2(core1)-Node2
Tx-5	λ_{35}-λ_{50}	1542.94-1559.79	50	16x10	Node-2	Node-1	Node2-MCF1(core6)-Node1

IV. CHANNEL PERFORMANCE

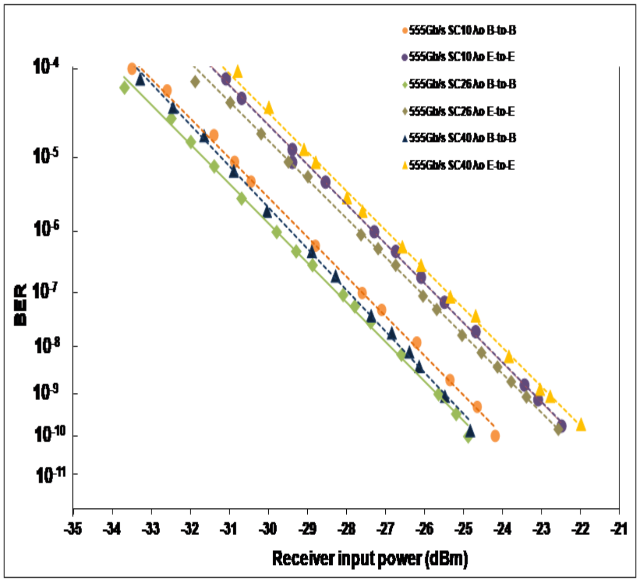
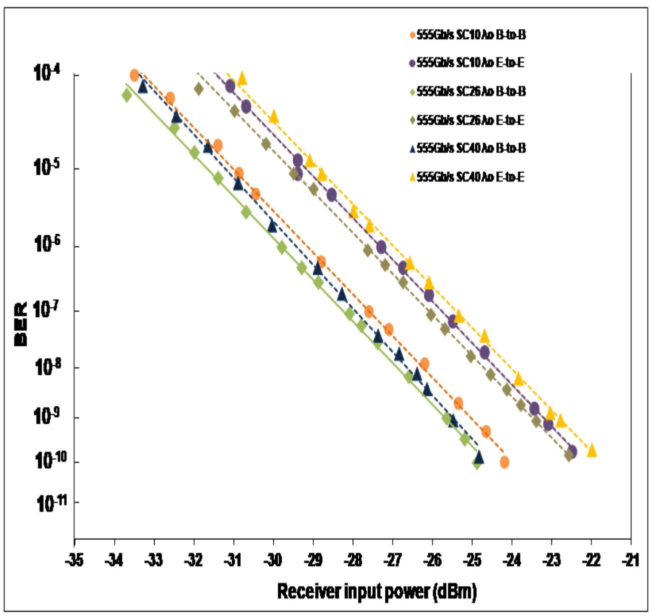


Figure 3: BER curves for (a) 10Gb/s and 42.7 Gb/s, (b) 555Gb/s



(10,26 and 40 sub-carriers

Figure 4: Back-to-back and end-to-end sensitivities of the 10Gb/s and 42.7Gb/s channels

Figure 3 shows typical end-to-end BER curves. In Figure.3 (a) the penalties of Tx-1 point A, 42.7 Gb/s ch#4, Tx-2 point B, 42.7 Gb/s ch#21, Tx-3 point C, 10 Gb/s ch#27, Tx-4-point D, 10 Gb/s ch#33 and Tx-5 point E, 10 Gb/s ch#42

For Tx-1 555 Gb/s (subcarrier# 10, subcarrier# 26, and subcarrier# 40) at point A in Fig. (b) In this case, BER was less than 2x10e-3 for all sub-carriers. Fig. 4 shows the sensitivity measurements of all 10.675Gb/s and 42.7Gb/s. A 2.5 dB penalty was applied to Tx-2 Channel 17, 42.7Gb/s signals using the lengthiest route (Node1-MCF1 core1-Node2-Node4). It was shown that the inter-core crosstalk penalty for 555Gb/s and 42.7Gb/s was minimal. Fig. 5 shows the channel OSNR after amplification and dispersion correction.

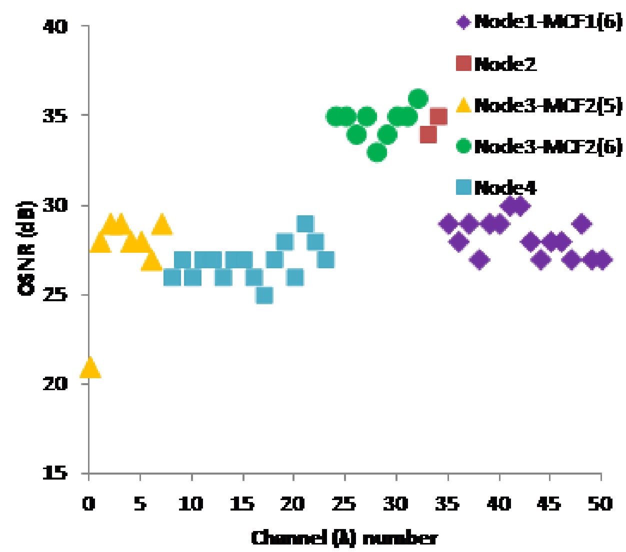


Figure 5: OSNR of each channel at destinations

V. CONCLUSION

For the first time, a directionless optical multi-dimensional SDM switching networking is proposed and investigated, using two 7 core MCF connections and 4 programmable nodes We successfully transmitted 1.8Tb/s data utilizing spectrum switching, provider traffic presenting services, and a 555Gb/s super channel. However, transporting signals with varying bit rates and modulation formats may result in spectrum fragmentation and increased obstruction. Smaller nodes may benefit from space defragmentation, reducing switching costs and enabling end-to-end services. All channels work properly with a maximum power penalty of 2.5 dB and no error.

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