High Speed System Transmission over 8-core Multicore MMF

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Abstract

We demonstrate the feasibility of supporting aggregated 800 Gbps in an 8-core multimode, multicore fiber assembly using existing high speed PAM4 modulation and bi-directional WDM transmission platform developed for 400GBASE-SR4.2 technology in IEEE P802.3cm. Analysis of the receiver QoS (Quality of service), receiver FEC error statistics and stressed eye closure (SECQ) suggest enough margin indicating a robust system performance up to a 32 m of transmission, providing a solution addressing numerous emerging datacenter problems with high density, small footprint, and high cooling efficiency.

Keywords: 400 Gb/s; 400GBASE-SR8.2; Datacenter; Datacom; Multicore MMF; PAM4; 4-level Pulse Amplitude Modulation; Short Wavelength Division Multiplexing; High Performance Computing (HPC); Serve Attachment; Server-to-Switch; Switch-to-switch

1. Introduction

Early work on multicore multimode fiber (coupled to VCSELs either directly or through a fan-in/out) supporting aggregated speed of 70 Gbps and 120 Gbps suggests its potential applications to address numerous emerging datacenter problems [1,2,3,4]. The proliferation of high-performance computing to support artificial intelligence driven applications requires higher capacity server and switches. This demand is driving server attachment speed to 50 and 100 Gbps but the interconnect distance of traditional passive copper cables is limited to 1.5 m at these data rates, shorter than required. Active copper cables and fiber arrays are potential solutions, but multicore multimode (MC-MMF) provides lower heat dissipation and less space supporting better air flow and cooling compared to the alternates. Moreover, MC-MMF is also attractive to support several high density short reach interconnect scenarios inside datacenter, e.g., MC-MMF fiber/cabling for in-row switch-to-server applications, for switch-to-switch application with connection to a pluggable transceiver, or with connection directly to the ASIC or an on-board optic, with duplex LC connector at the faceplate to reduce power dissipation required to drive the electrical signals over the long copper traces. In this paper, MC-MMF is shown to support high bandwidth as both PAM-4 modulation and bi-directional WDM transmission is demonstrated using a 400GBASE-SR4.2 transceiver, over lengths suitable for these applications.

2. Description of the 8-core MC-MCF Assembly

The 8-core MC-MMF (Figure 1a) has eight graded-index Ge-doped cores of 26 µm in diameter and Numerical Aperture (NA) = 0.3 each. The pitch between adjacent core is 41.6 µm. The glass outer diameter

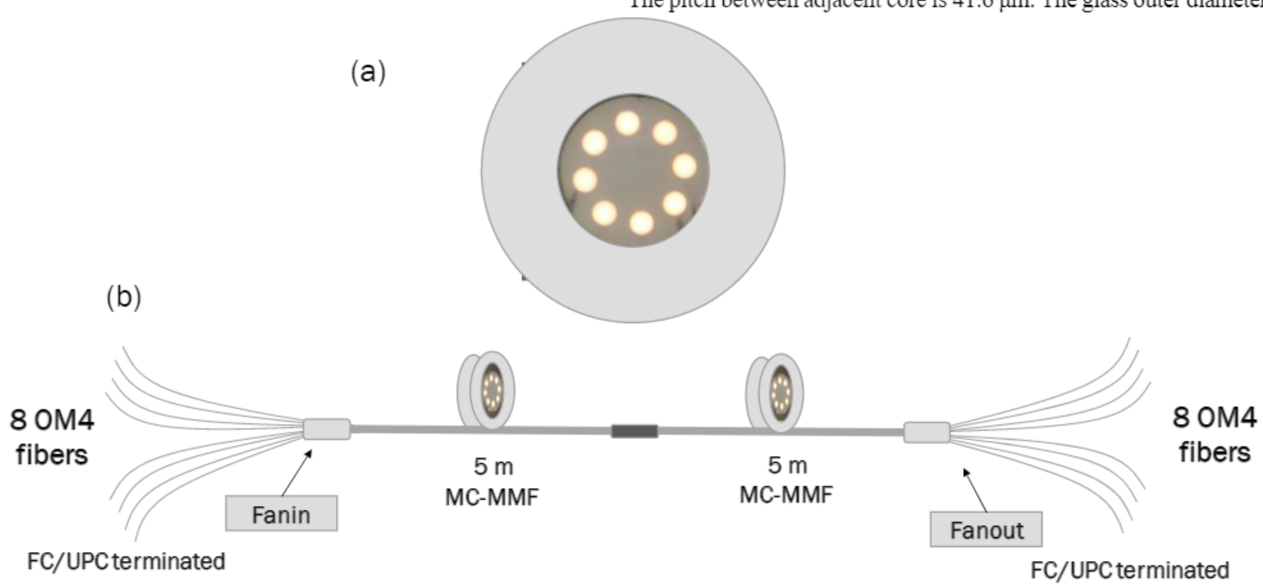

Figure 1. (a) Cross view of the 8-core MC-MMF. (b) Schematic of the 8-core MC-MMF assembly.

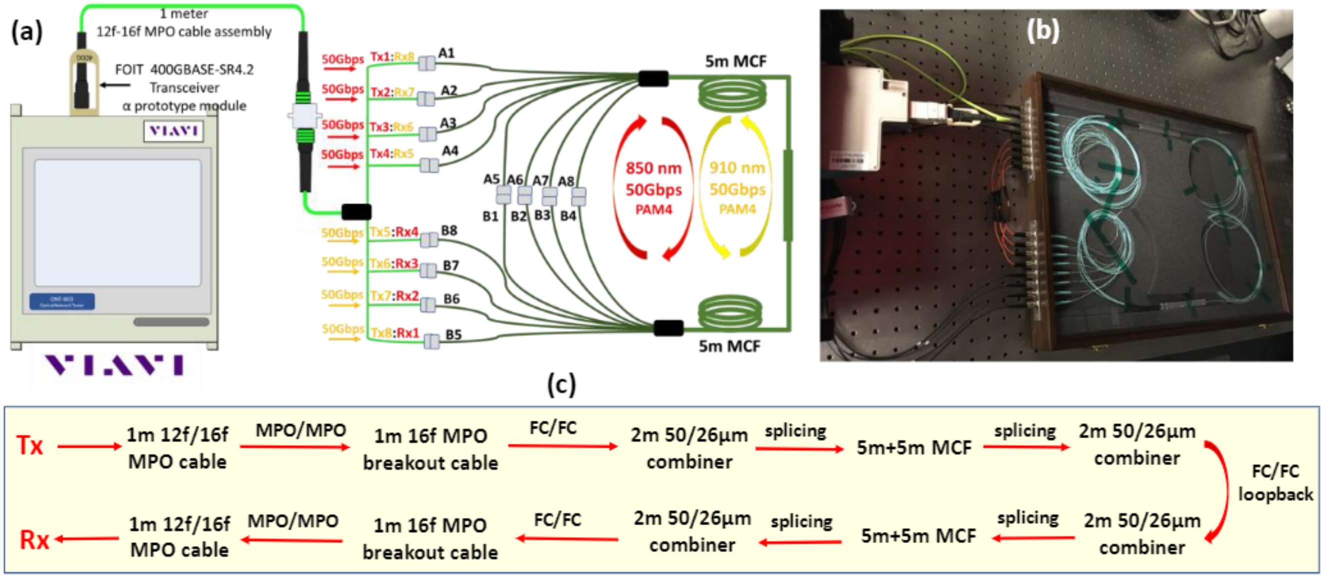

Figure 2. (a) Schematic and (b) image of 400GBASE-SR4.2 transmission over 8-core MC MMF. (c) flow chart of each 50Gbps PAM4 optical signal through the optical link.

is 165 μm and the coated fiber outer diameter is 300 μm. An eight 50/125 μm MMFs fan-in (denoted as port A) and fan-out (denoted as port B) combiner are spliced to both ends of the MCF to form an assembly. One end of the eight 50/125 μm MMFs is terminated with a FC/UPC connector each. The other ends of the eight 50/125 μm MMFs are taped down to 26 μm in diameter each and combined into one fiber to splice to the 8-core MC-MMF. The length of the MC-MMF is 10-meter including two 5-meter sections spliced together and the length of the 50/125 μm MMFs in fan-in/fan-out is 2 meter each. The loss from port A of the fan-in to port B of the fan-out is < 5 dB and the cross talk is < -30 dB.

3. High Speed System Transmission Experiment over 8-core MC-MMF

3.1 Experimental Setup

400 Gbps layer 2/3 full ethernet traffic is generated and received by a Viavi 400 G Optical Network Tester (ONT). The Viavi generated 400 Gbps electrical signals is loaded to a prototype 400GBASE-SR4.2 transceiver (FOIT) through a CFP-to-QSFP-DD adaptor. Transmitter center wavelength, RMS spectral width and optical power are shown in table 1. Encircled flux (EF) meets IEEE P802.3cm standard.

Tx #	1	2	3	4	5	6	7	8
λ_c(nm)	858.3	858.3	858.3	858.3	910.4	910.5	910.5	910.5
RMS (nm)	0.39	0.29	0.32	0.32	0.51	0.45	0.45	0.48
power (dBm)	0.29	0.62	0.63	0.66	0.61	0.55	0.34	0.56

Table 1. Transmitter characteristics.

A 1-meter MPO-12 (PC, female) to MPO-16 (PC, male) jumper is used to interface between the 400GBASE-SR4.2 module and a MPO16 (UPC, female) to sixteen 50/125 μm breakout assembly. The 50/125 μm MMFs are terminated with FC/UPC connector each. Eight out of 16 MMFs of the MPO16 breakout assembly are active in transmitting and receiving optical signals. Through four of the eight 50/125 μm MMFs of the fan-in, 400 Gbps 850 nm signals (4 × 50 Gbps PAM4) are coupled into four cores of the MCF at A-ports (A1 to A4), looped back to the MCF by connecting four B-ports (B1-B4) to the other four A-ports (A5-A8) and eventually received at Rx1-4 through the B5-B8 ports. 910 nm 50G PAM4 signals transmit through the same optical path in the opposite direction. Figure 2 shows the diagram (a) and image (b) of the system transmission setup and the flow chart (c) of each 50 Gbps PAM4 optical signal through the optical link.

Including all jumpers and MCF, the total transmission distance of 400 Gbps optical traffic is 32 meters where 20-meters is in the 8-core MC-MMF, 8 m in the fan-in/fan-out and 4 meters in 50/125 μm MMF MPO jumpers. The optical signals go through 2 MPO connections, 4 FC/FC connections, 4 fan-in/fan-out combiner splicing and 2 MCF-MCF splicing.

3.2 Results and Discussions

3.2.1 Receiver QoS

400 Gbps layer 2/3 Ethernet traffic at 100% bandwidth utilization is transmitted using the MC-MMF setup described in the previous section. All layers are ok after more than 17 hours transmission, free from any bit error and frame error. The screen capture of the Rx QoS in MAC/IP layer is shown in Figure 3. The total bit errors corrected is below 5×10^{-7} prior FEC, three orders better than KP4 FEC threshold, only slightly increased than the bit errors introduced by the transmitter itself (1.89×10^{-7}). No un-correctable errors are recorded. Note that all eight cores of the MCF are active simultaneously and all optical PAM4 signals go through the MCF to MMF fan-in/fan-out twice and the MCF-MCF splice twice. This is a more stressed condition in the MCF link connection than loading 800 Gbps signals to 8 cores of MCF using two 400GBASE-SR4.2 transceivers (100 Gbps BiDi transmission per core). Thus, it demonstrated the capability of the 8-core MCF to carry 800 Gbps aggregated signals. Error free transmission of 400 Gbps ethernet traffic over a long time

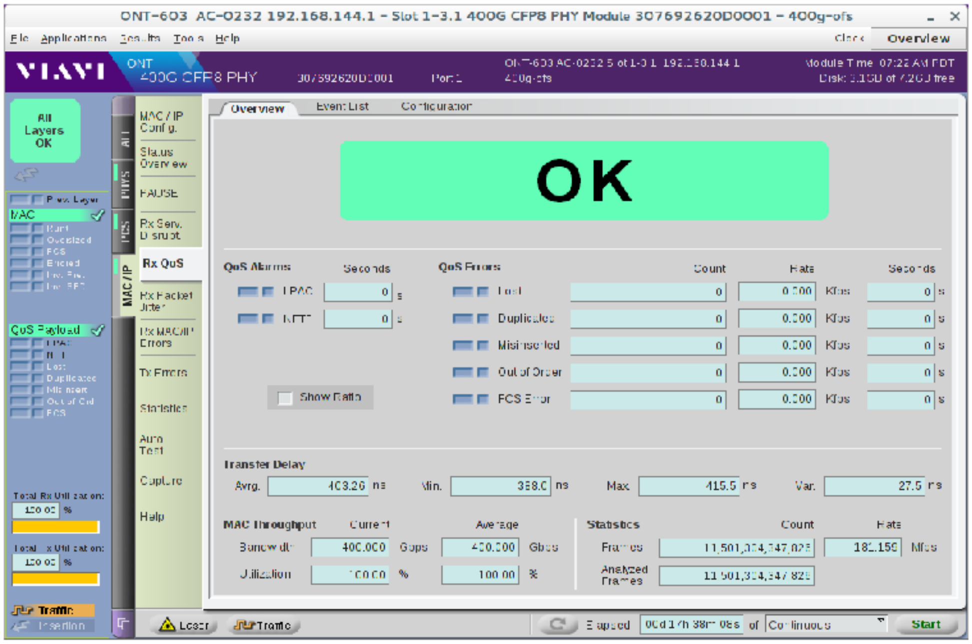

Figure 3. Screen capture of Rx QoS in MAC/IP layer after 17 hours 38 minutes error free transmission.

is repeated in four different 8-core MC-MMF assemblies using the same assembly design and system testing setup described in this paper.

3.2.2 Attenuation

The total attenuation including fan-in/fan-out, MCF and all connections/splices of the optical link configuration shown in Figure 2 is 1.26 dB (min) to 2.55 dB (max) at 910 nm and 2.48 dB (min) to 3.56 dB (max) at 850 nm using the eight transmitters of the prototype 400GBASE-SR4.2 transceiver.

3.2.3 Noise Power due to Inter-core Crosstalk and Receiver FEC Error Statistics

No. of Symbols	bkbk	MCF
0	99.88011200	99.84458900
1	0.11959400	0.15484400
2	0.00028500	0.00055900
3	0.00000300	0.00000800
4	0.00000000	0.00000032
5	0.00000000	0.00000002
6	0.00000000	0.00000000
7	0.00000000	0.00000000
8	0.00000000	0.00000000
9	0.00000000	0.00000000
10	0.00000000	0.00000000
11	0.00000000	0.00000000
12	0.00000000	0.00000000
13	0.00000000	0.00000000
14	0.00000000	0.00000000
15	0.00000000	0.00000000

Table 2. Receiver FEC error statistics in percentage for bk2bk and MC-MMF link shown in Figure 2.

The noise power introduced by the inter-core crosstalk is estimated at each receiving end with all transmitters connected except the one for the channel under test. The noise power leaked from the other cores for the configuration in Figure 2 is measured to be -30.13 dBm (min) to -27.87 dBm (max) at 850 nm and -31.28 dBm (min) to -26.35 dBm (max) at 910 nm. (Note that since two cores instead of one core are in dark in the loop-back testing configuration, the noise power estimated are from six out of seven cores introducing inter-core crosstalk. The noise power experienced in the transmission with all channels running is expected to be slightly higher than the above measured value.) Due to the distributed nature of the inter-core crosstalk, the negative impact of the noise introduced by the crosstalk is expected to be demonstrated as longer errored symbols. Table 2 shows a comparison of the receiver FEC error statistics (in percentage) for the bk2bk (4 m) and with MC-MMF (32 m). Bk2bk has errored symbols up to symbol # 3 while MC-MMF link spreads the errored symbols to # 4 & 5. However, there is no error for the rest 10 symbols (# 6-15) indicating a robust 400 G transmission and a minor negative impact introduced by the crosstalk.

3.2.4 PAM4 Eyes and Stressed Eye Closure (SECQ)

Optical eyes at each FC connector of the fan-out is measured using a Keysight 81000D oscilloscope. The transmitter is a FOIT 100GBASE-BiDi module. The testing setup configuration is the same as in reference [5] with the 8-core MC-MMF assembly replacing the OM5 fiber under test. Four port B of the fanout are connected to four port A of the fan-in, same as in the configuration described in Figure 2. Optical PAM4 eyes after 5-taps FFE (as recommended for TDEXQ measurements in IEEE P802.3 standard) is measured at each FC connector of the fan-in (910 nm) and fan-out (850 nm) using a Keysight 81000D Oscilloscope (shown in Figure 4: left -910 nm and right-850 nm). SECQ seen by the receiver after 30 m transmission is 2.06 dB, 2.07 dB, 2.02 dB and 2.19 dB at 850 nm and 1.87 dB, 2.00 dB, 2.43 dB, and 1.89 dB at 910 nm. The maximum 2.43 dB is 2 dB less than the 4.5 dB maximum SECQ specification for 400GBASE-SR4.2 in IEEE P802.3 cm standard, indicating enough margin for a robust system performance.

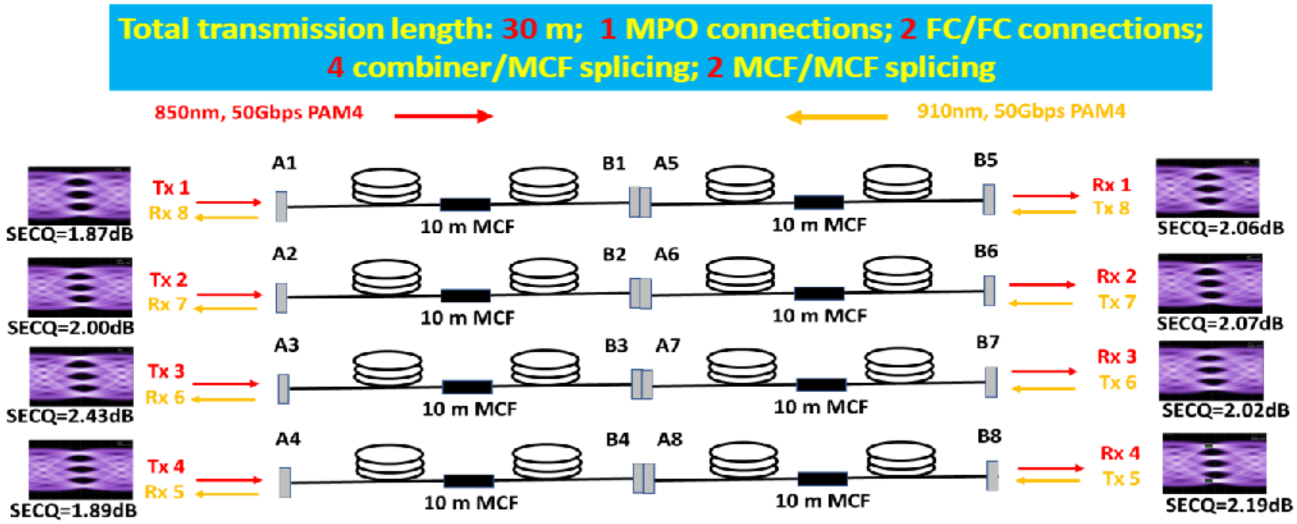

Figure 4. SECQ seen after 30 m transmission. Note that 50/125 am jumpers interfacing transmitter/scope optical head and of the fan-in/out are taken account in the 30 m length but not shown in the graph for simplicity.

4. Conclusions

400 Gbps layer2/3 full ethernet traffic loaded to a protype 400GBASE-SR4.2 transceiver is successfully transmitted over 32 m parallel MMF fiber/cabling including 20 m in an 8-core MC-MMF, 8 m in fan-in/fan-out and 6 m in OM4 MMF MPO cabling. Receiver QoS in MAC/IP layer, attenuation, noise power due to inter-core crosstalk and SECQ are measured. The test passes the receiver QoS for an extended time (>17 hours) and is repeatable for four 8-core MC-MMF assemblies with the same design. Receiver FEC error statistics shows a negative but minor impact from the inter-core crosstalk. Max SECQ seen after 30 m transmission is 2 dB below the specification of 4.5 dB for IEEE P802.3 cm standards, demonstrating enough margin for a robust performance over 30 m, a distance suitable for or exceeding the need of several datacom applications including HPC server attachment and switch-switch interconnects in datacenter. The optical link has all 8-cores active simultaneously and includes multiple connections/splices (6 MPO or FC connections and 6 MC-MC splices). This is a more stressed condition than having 8-cores carrying 2 × 400 Gbps signals using two 400GBASE-SR4.2 transceivers. Thus, it indicates the feasibility of the 8-core MC-MMF supporting 800 Gbps aggregated speed using existing PAM4 and WDM platform developed for 400GBASE-SR4.2 VCSEL-MMF technology for datacom/HPC applications.

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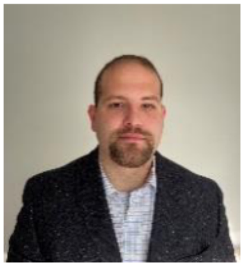

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